TRANSACTIONS

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

VOLUME 32

THIRTY-SECOND ANNUAL MEETING
BUFFALO, N. Y., JANUARY 27-29, 1926

SEMI-ANNUAL MEETING
LEXINGTON, KY., MAY 26-28, 1926

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1926

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TRANSACTIONS

of

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

No. 734

THE THIRTY-SECOND ANNUAL MEETING, 1926

THE A.S.H.&V.E. made a remarkable showing when 413 members and guests assembled at the Hotel Statler, Buffalo, N. Y., to open the 32nd Annual Meeting of the Society, during which papers for the betterment of human comfort and health were presented, followed by interesting discussions.

One session was devoted to each of the important questions in the minds of the members, including the present status of ventilation presented by Prof. C.-E. A. Winslow, Yale University, whose views on the subject resulted in vigorous replies from physiologists, consulting engineers, and health officials. The Society expressed the idea that it would welcome scientific data from other sources and would gladly coöperate with other organizations. Other topics to which a session each was given are the research results on several phases of both heating and ventilation, including radiation, infiltration, insulation, heat humidity and air movements, etc., and Amendments to the Constitution and By-Laws of the Society.

The first general session at Buffalo convened on Wednesday morning, January 27, at 10:30 o'clock, with Vice-Pres. W. H. Driscoll presiding. Mr. Driscoll introduced W. G. Fraser, who welcomed the guests to Buffalo, and who later called upon Roswell Farnham, president of the Western New York Chapter, to take charge of the opening ceremonies.

An address of welcome was given by P. J. Kuhn, and R. B. Flershem presented the members and guests of the Society with the keys of the city on behalf of Mayor Schwab, of Buffalo, who was unable to be present.

The reports of the Council, Secretary, Finance Committee, Certified Public Accountant, Publication Committee, Committee on Increase of Membership, and the report of the Tellers of Election, followed immediately after Mr. Flershem's address of welcome.

The second session was called to order by Vice-President Driscoll, who gave a brief announcement concerning the rules governing professional sessions. This

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session comprised the reading of various papers, the first presented by Dr. Chas. W. Brabbée, followed by R. V. Frost, E. H. Whittemore, and R. H. Heilman.

Pres. S. E. Dibble opened the third session on Thursday morning, January 28, with the reading of the annual report of the President, followed by the report of Committee on Research presented by the chairman, W. H. Driscoll.

Report of Committee on Research

With the most substantial support that has ever been accorded the Laboratory by the members of our Society, the Committee presents to you today the most hopeful and encouraging report of Laboratory affairs that has ever been presented to the Society.

The action taken by the Society one year ago, whereby the members voted to tax themselves the sum of $10.00 each in order to provide a basic annual income for the Laboratory, not only reflected credit on the members, but served notice to the world in general, and the engineering profession in particular, that this Society had definite aims and purposes, and that it was prepared to insure the accomplishment of those purposes at any cost.

The action taken by the Society at that time saved the Laboratory from complete destruction, because every other method that had been tried for providing the required basic income had been found wanting and we were facing a condition of bankruptcy.

This condition was immediately corrected and the interest of friends of the Laboratory was aroused to such an extent, that, at the annual meeting in Boston, or shortly thereafter, we received voluntary contributions from the following:

	Amount subscribed, 1925	Amount paid
Aerofin Corporation	$ 100.00	$ 100.00
American Blower Co	1000.00	750.00
Babcock & Wilcox Co	250.00	250.00
Barnes & Jones	200.00	200.00
Buffalo Forge Co	1000.00	1000.00
Alice G. Bryant	100.00	100.00
E. K. Campbell Htg. Co	50.00	50.00
Carrier Engr. Corporation	300.00	300.00
C. F. Eveleth	20.00	20.00
Fowler & Wolff Mfg. Co	100.00	100.00
Fulton Company	250.00	250.00
General Electric Co	500.00	500.00
Heat. & Piping Contr. Nat. Assn	500.00	500.00
H. & P. Contractors Assn. of Chicago	1000.00	1000.00
Hoffman Specialty Company	1000.00	1000.00
Johnson Service Company	500.00	500.00
Kansas City Chapter	408.86	408.86
Kewanee Boiler Co	1000.00	1000.00
Langenberg, E. F. Mfg. Co	100.00	100.00
Massachusetts Chapter	1000.00	1000.00
Mensing, F. D	150.00	150.00
Midwest Air Filter Co	250.00	250.00
Monarch Weather Strip Co	250.00	250.00
Nash Engr. Corporation	250.00	250.00
National Boiler & Rad. Mfg. Assn	2500.00	2500.00
Nesbitt, J. J. Co	150.00	150.00
Reed Filter Company	250.00	250.00
Robinson, D. P. Company, Inc	100.00	100.00
Sterling Engr. Company	100.00	100.00
Sturtevant, B. F. Co	1000.00	1000.00
Thermal Appliance Co	50.00	50.00
Warren Webster Co	1000.00	1000.00
Welamb Victor	50.00	50.00
York Heating & Ventilating Company	100.00	100.00
Total Amount Received		$15,328.86

Every contributor whose name is included in this list has met his obligations in full to date. In other words, payments for 1925 have been met on a 100% basis and the Committee cannot find words to express its appreciation to the contributors who extended their support at a critical period in the life of the Laboratory.

Our auditor has prepared a complete financial statement of the Laboratory and this will be published in the March JOURNAL. This will indicate that we have cash on hand in excess of $5000.00. In addition to this, however, we have due us from the General Fund of the Society approximately $7000.00, which represents profits made on THE GUIDES of 1924 and 1925, and $6000.00 which represents the proportion of members' dues due the Laboratory. Transfer of these accounts from the General Fund to the Research Fund is made by the Council when a request for same is made by the Committee on Research. This request will be made after the organization of the new Council and the Committee on Research, immediately following the Annual Meeting. We are, therefore, starting this year with approximately $18,000.00 in cash and with the fixed income from dues.

When it is recalled that two years ago we had not enough cash on hand to pay our expenses for another month, that we had no income to depend on, and that only by the dint of the strenuous effort on the part of members throughout the country were we able to keep our head above water during that year, and that one year ago we were still on the verge of bankruptcy, you will realize that we have turned the corner and are on our way back.

This is indicated not only by the splendid financial report, but by the way in which we are now organized to bring the members into closer contact with the Laboratory and make the service of our members an important part of the Laboratory work. This is being accomplished through the tremendous activity and energy of the various committees whose names will be presented further on in the report.

With the assurance that our problems of finance had at last taken a turn for the better, the Committee began to make preparations to put the Laboratory into action on a basis that would insure its operation with the utmost efficiency.

As the members have already been advised, the next most serious problem was the selection of a director to succeed Dean Anderson, who had served the Society in a most splendid way, but who found it necessary to definitely withdraw and devote his time to the work of educating young men, which for thirty years had engaged his attention at Lexington, Kentucky.

The Committee proceeded to handle this problem with the utmost care and deliberation because it felt that it must seek the highest type of man that could be obtained for the position. The Committee conferred with and tendered the appointment to L. A. Harding, Prof. A. C. Willard, Prof. Hoffman, and Prof. Giesecke, but was disappointed in each case to find that the party in question, while fully appreciative of the honor of such an appointment and appreciative of the possibilities of the position, was reluctantly compelled, because of personal reasons, to decline the offer that was made.

Special Committees were appointed and worked for months on this problem and the names of many candidates were considered. The name of Ferry C. Houghten was continually before the Committee, but the fact that Mr. Houghten was serving the Society as its Secretary and his removal from that position would complicate matters at Headquarter's Office delayed the final selection.

An arrangement was finally effected with the Council of the Society whereby Mr. Houghten could be relieved of his duties as Secretary and the appointment was tendered to and accepted by him. As soon as the details at Headquarter's Office were cleared up, Mr. Houghten proceeded to Pittsburgh on September 1st and took over the duties of Director.

In the meantime the Committee felt that it was not justified in proceeding with a definite program of action at the Laboratory until the problem of the directorship was solved and until the new director had taken hold and could be consulted as to the program. As a result, activities at the Laboratory were restrained and the program of actual work accomplished has perhaps fallen short of what the members may have expected. The Committee, however, felt justified in proceeding slowly and cautiously, first, because the selection of the Director was of so much importance that caution and deliberation were essential, and, second, because the Research funds were at such a low ebb that it was quite important that a reserve fund be developed and the procedure that was being followed in the matter was automatically helping to develop such a fund.

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In its studies of the problems of administration, the Research Committee had determined that the work of the Laboratory was the work of the Society, and the results obtained at the Laboratory would be infinitely more valuable if the members of the Society could be aroused to active cooperation in the work of Research. As a step in this direction, it was determined that no problem would hereafter be undertaken at the Laboratory until a technical Committee had been appointed to prepare an outline of the manner in which the problem was to be conducted and to serve as an advisory committee to the Director and his assistants in the carrying on of the problem in question.

Four problems of immediate importance presented themselves. Technical committees were appointed and the work gotten under way at the earliest possible moment. These problems were as follows:

PROBLEM "A"

THE TESTING OF STEAM AND HOT WATER TYPES OF RADIATORS FOR THE PURPOSE OF DETERMINING THEIR RELATIVE EFFICIENCIES PARTICULARLY WHEN USED ON ONE PIPE JOBS

PROBLEM "B"

CRITICAL VELOCITIES

PROBLEM "C"

INFILTRATION

PROBLEM "D"

TEMPERATURE, HUMIDITY, AND AIR MOTION

The names of the members of the Technical Advisory Committees appointed to handle these problems were as follows:

COMMITTEE ON RADIATION

R. V. Frost, *Chairman*

R. C. Bolsinger
Dr. Charles Brabbée
G. M. Getschow
E. H. Lockwood
J. F. McIntire
F. B. Rowley

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C. V. Haynes
J. H. Walker
T. M. Dugan

COMMITTEE ON INFILTRATION

A. C. Willard, *Chairman*

W. S. Timmis
L. A. Harding
E. B. Langenberg
D. Knickerbacker Boyd
A. P. Kratz
Hans J. Meyer

COMMITTEE ON TEMPERATURE, HUMIDITY AND AIR MOTION

W. H. Carrier, *Chairman*

Dr. E. V. Hill
Burt S. Harrison
Dean F. Paul Anderson
W. L. Fleisher
John F. Hale
E. S. Hallett

The report of these Committees will in each instance be made by the Chairman of such Committee and this will probably be followed in the future in connection with Laboratory reports. The Committee on Research feels that only by imposing definite obligations on Society members will the active cooperation of the members be obtained and the duty of the Technical Advisory Committee will include, among other things, responsibility for delivering at our meetings all papers emanating from the Laboratory. These Committees will take upon themselves the duty of inviting chapters and individual members to furnish them with such information as they may have in connection with the subjects under consideration.

It is hoped that the members of the Society will encourage the hard working members of these Committees by rendering all possible assistance when called for.

A very important sub-committee of the Committee on Research is the Committee on Subjects. The duty of this Committee is to obtain from every possible source suggestions as to matters that should be investigated through the Laboratory, to give

consideration to these suggestions and to make recommendations to the Committee on Research as to the subjects to be investigated and the order of their importance. This Committee is made up as follows:

COMMITTEE ON SUBJECTS
S. R. Lewis, *Chairman*

J. A. Donnelly
D. S. Boyden
W. G. Fraser
E. Szekely
J. R. McColl
N. W. Downes

The Committee on Research wishes not only to express its thanks to the members of these Committees for accepting their appointments, but to call the attention of the members to the fact that these Committees have taken hold of their work with amazing energy, and deserve the appreciation of every member of the Society.

Research Residence

The suggestion that we erect a Research Residence, for the purpose of making investigations in connection with the problem of heating the home has received such widespread attention, and has been the subject of such increasing interest, that your Committee feels obligated to continue its efforts to find some means of financing such a proposition, without imposing a further burden on our members, and without affecting the normal channels by which our Laboratory is financed.

The efforts of the Committee in this direction up to the present time have not been successful, but the Committee is exceedingly hopeful as to the outcome of its work in this direction, and invites assistance and suggestions from members, both with respect to the matter of financing, and with respect to the objects to be accomplished.

Cooperative Work with Universities

It is the feeling of the Committee that the work at the Laboratory can be greatly increased by soliciting the cooperation of the various universities of the country in connection with problems where such cooperative work can be properly carried on. Interesting developments in this direction will undoubtedly take place during the coming year.

The Testing of Commercial Devices

Your Committee has been authorized by the Society under a resolution passed at the Annual Meeting in January, 1924, to proceed with the testing of devices and equipment used in the heating industry under conditions and restrictions that are clearly outlined in the resolution. The Committee is not proceeding with any work of this nature for several reasons.

In the first place, no such devices are to be tested until a code covering the testing of such equipment has been prepared, and the approval of such a code by the Society has been obtained. Codes covering the testing of boilers and of fans have been prepared and approved but, up to this time, no codes have been prepared covering the testing of other equipment. In the second place, our arrangement with the Bureau of Mines does not permit of the carrying out of such tests at the Laboratory at Pittsburgh, and work of this kind will have to be carried out as part of the scheme of cooperation with universities.

Finances

While the present financial condition of the Laboratory is most hopeful and satisfactory, your Committee must look forward to the possibility of increased revenue being obtained for the purpose of enlarging and extending the work of the Laboratory.

It is evident that the work of the Laboratory can be greatly enlarged, and that additional subscriptions that may be obtained can be utilized on the basis of 100% productive activity. There is, necessarily, a certain amount of overhead expense in connection with the conduct of the Laboratory, whether its activities be great or small, and the activities of the Laboratory can be largely increased without any corresponding increase in what might be termed "non-productive expense."

Your committee feels that the expense of the work in which we are engaged is prop-

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erly an obligation of the heating industry. The results that will be obtained at the Laboratory will, undoubtedly, be of benefit to the world in general, but to the heating industry in particular.

Under the circumstances, we are fully justified in expecting the support of the industry, and it is hoped that, from this time on, the work of the Laboratory will compel the respect and attention of those who are at present skeptical or, at least, not sympathetic to the purposes of the Laboratory, and that, in due time, we will find them among its supporters.

As the work proceeds, and the expenses of the Laboratory increase, we may be compelled to make a direct appeal to the manufacturers and others interested in the heating industry. In the meantime, it might be advisable for us to state that our subscription lists are still open for those members, and others, who wish to add their names to the roll, or to increase subscriptions already made.

Respectfully submitted,

COMMITTEE ON RESEARCH,

W. H. DRISCOLL, *Chairman.*

F. C. Houghten, director of the Research Laboratory, then told of the work at the Laboratory, presenting in detail the problems under consideration and the methods of procedure. The session adjourned at 1:00 o'clock.

The fourth session convened on Thursday afternoon when President Dibble introduced A. C. Fieldner, superintendent of the Bureau of Mines Experiment Station who explained the problems of ventilation in New York-New Jersey Vehicular Tunnel. Dr. R. R. Sayers was the next speaker, and was followed by Prof. C.-E. A. Winslow, who presented his paper to a very enthusiastic audience. A series of discussions followed Professor Winslow's paper before the conclusion of the session.

The following resolution proposed by F. D. Mensing, seconded by Thornton Lewis, was carried.

Resolved, that the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS appreciates the fact that the *American Public Health Association* earnestly desires to endorse that condition of ventilation which is calculated to give greatest health and comfort to the occupants of places of assembly. The AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS has been working diligently for many years through the Research Laboratory in connection with the Bureau of Mines and the U. S. Public Health Service to determine these facts scientifically.

Therefore, the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS solicits the cooperation of the *American Public Health Association* in making this determination.

The following resolution offered by W. A. Rowe, seconded by J. A. Donnelly, was carried.

Resolved, that it is the sense of this meeting that it would be a grave mistake to advocate the repeal of present laws which require installations in accordance with present standards until something better than present practices can be agreed upon; that present ventilation standards are the result of many years' practical experience; that present laws based on those standards have been a positive influence for good; that the wholesale letting down of the bars to permit anything so indefinite as "Window Ventilation" would be a step backward and would result in a chaotic condition detrimental to the public health and best interest of the country.

Thornton Lewis suggested the following resolution, seconded by Dr. E. V. Hill, which was carried when voted upon.

> *Resolved,* that the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS welcomes definite air supply information from the *American Public Health Association,* but most definitely disagrees with the suggestion that any consistent ventilation can be obtained by air admission through windows with gravity vent flues.

On Friday morning, January 29, the fifth session convened with the reading of reports by Perry West, H. C. Eicher and H. W. Brooks. Perry West also gave the report of Committee to Confer with Architects.

The first of the technical papers to be presented was given by the author J. E. Emswiler, University of Michigan, which was followed by C. A. Bulkeley's paper.

The next important business was the discussion of the Amendments to the Constitution and Dr. E. V. Hill, Chicago, chairman of the Committee on Revision of the Constitution was asked to make his report. He pointed out the important features and recommendations made regarding the amendments which had been placed before the membership in accordance with the Constitution. About one-third of the 200 present expressed their opinions in this important question of changing the Constitution and as a result of the suggestions offered, the following changes were authorized:

Amendment No. I

ARTICLE IV, *Section 1* now reads:

"The affairs of the Society shall be managed by a Board of Directors chosen from among the persons entitled to vote, which shall be styled 'the Council.' It shall consist of twelve (12) members, four of whom are the duly elected officers. The Secretary may take part in the deliberations of the Council but shall have no vote therein."

It is proposed that *Section 1* shall be amended to read:

"The affairs of the Society shall be managed by a Board of Directors, chosen from among the persons entitled to vote, which shall be styled 'the Council.' It shall consist of the President, First Vice-president, Second Vice-president, Treasurer and 12 elected members. The elected members shall serve three years, except, those elected the first year of which 4 shall be elected for a term of three years; 4 for a term of two years, and 4 for a term of one year, and thereafter as provided for in Article V. The Secretary may take part in the deliberation of the Council, but shall have no vote therein."

Amendment No. II

ARTICLE V, *Section 1-e* now reads:

"Seven members of the Council all of whom shall hold office for one year."

This to be amended to read:

"Four members of the Council all of whom shall hold office for three years."

Amendment No. III

ARTICLE V, *Section 1-f:*

"The retiring President shall without election become an additional member of the Council for one year."

Amendment No. IV

ARTICLE 6, Meetings: *Section 4:*

"Whenever the Council or two-thirds of the members present and voting at any annual or semi-annual meeting refer any question, except an amendment to the constitution, to the membership at

large, it shall be submitted in writing, in such form as directed by the Council, to all members entitled to vote and decided by a majority of the letter ballots received."

Amendment No. V

ARTICLE 6, Meetings: *Section 1*, now reads:

"The Society shall hold two meetings each year, the annual meeting shall begin in the city of New York, New York, on the fourth Tuesday in January continuing from day to day as the Council may arrange."

This to be amended to read:

"The Society shall hold two meetings each year, the annual meeting to commence during the week beginning with the fourth Monday in January at such place as the Council may elect and continuing from day to day as the Council may arrange.

These amendments as finally adopted at the meeting will be submitted to the entire membership for vote before April 15, 1926.

On motion of Mr. Gant, seconded by Dr. Hill, the amendments 6 and 7 were rejected.

At the conclusion of the session, E. B. Langenberg, St. Louis, offered the following resolution, seconded by Benjamin Adams, Philadelphia.

Whereas, the wide publicity that has been given to open-window ventilation because of the report of the New York State Commission and because of action taken by the Illinois Medical Association and the *American Public Health Association* at Bloomington and St. Louis, and

Whereas, this Society has not as yet taken any definite action to refute the claims that have been made;

Therefore be it Resolved: that the A.S.H.&V.E. through its Council and Research Advisory Committee take action that will cause a survey to be made of the entire question of the heating and ventilating of schools as at present in use for the purpose of determining facts as now exist and to further bring out new requirements and to report on this work to the Society in 1927.

Thornton Lewis presented the following amendments to the By-Laws which had been placed before the membership in the proper manner and on motion of Mr. Lewis seconded by Prof. Dibble these were approved.

Section 6—to be amended to read:

All applications for membership are to be sent to the Secretary and the names of applicants and their references shall be printed in the next issue of THE JOURNAL or sent to the members in other approved manner as ordered by the Council. When replies are received from references, the Candidate's application shall be submitted to and acted upon by the Membership Committee as soon as possible.

Section 7—to be amended to read:

When the Membership Committee has acted favorably upon a Candidate's application and assigned his grade the Council shall vote upon the election of the proposed Candidate for membership by letter ballot.

On motion of Mr. Langenberg, seconded by Mr. Gant it was recommended that the Council favor the invitation of the St. Louis Chapter to hold the Annual Meeting 1927 in that city. The meeting then adjourned.

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PROGRAM ANNUAL MEETING, 1926

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

Hotel Statler, Buffalo, N. Y.

First Session

Tuesday, January 26, 10 a.m.

Engineering Societies Building, New York, N. Y.

Second Session

Wednesday, January 27, 8.30 a.m.

Hotel Statler, Buffalo, N. Y.

Registration
Addresses of Welcome, Mayor F. X. Schwab; N. Loring Danforth, President Buffalo Chamber of Commerce; A. A. Landon for Western N. Y. Chapter
Address of President, S. E. Dibble
Report of Council
Report of Secretary
Report of Treasurer
Report of Committees
a. Executive
b. Finance
c. Publication
d. Membership
e. Special Committee on Printing Code of Minimum Requirements for Heating and Ventilation of Buildings

Third Session

Wednesday, January 27, 2 p.m.

PROFESSIONAL SESSION

Paper:
The Heating Effect of Radiators, Dr. Chas. W. Brabbée

Paper:
A Proposed Code for Rating and Testing Radiators, R. V. Frost

Paper:
Forced Hot Water System Heats Ford's Twin Cities Plant, E. H. Whittemore

Paper:
The Advantages of Heat Insulation in Hotels, Apartment Houses, and Private Residences, R. H. Heilman

Fourth Session

Thursday, January 28, 9.30 a.m.

RESEARCH SESSION

Scope of Bureau of Mines Tunnel Ventilation Investigation, A. C. Fieldner
Motion Picture—New York and New Jersey Vehicular Tunnel
Summary of Results of Tunnel Investigation, Dr. R. R. Sayers
Report of Committee on Research—W. H. Driscoll, Chairman
Report of Technical Advisory Committees: 1. Heat, Humidity, and Air Motion, W. H. Carrier. 2. Infiltration, Prof. A. C. Willard. 3. Radiation, R. V. Frost.
Summary of Laboratory Work, by F. C. Houghten, Director of Research

Fifth Session

Thursday, January 28, 2 p.m.

PROFESSIONAL SESSION

Objects and Methods of Ventilation, by Prof. C.-E. A. Winslow.
Discussion of the Present Status of Ventilation, Perry West, D. D. Kimball, Dr. E. V. Hill, and others.

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Sixth Session

Friday, January 29, 10 a.m.

Paper:
The Neutral Zone in Ventilation, J. E. Emswiler
Discussion of Amendments to Constitution and By-Laws

Seventh Session

Friday, January 29, 2 p.m.

PROFESSIONAL SESSION

Paper:
Ozone Applications in Ventilation, F. E. Hartman

Paper:
Temperature Conditions in Rooms Heated by Warm Air Systems, V. S. Day
Installation of Officers
New Business.

No. 735

THE HEATING EFFECT OF RADIATORS

with a

PRACTICAL METHOD FOR TESTING RADIATORS BY COMPARISON

By DR. C. W. BRABBÉE, BRONXVILLE, NEW YORK
MEMBER

IN 1896 Prof. Dr. Rietschel published in Berlin, Germany, the results[1] of a large number of tests on radiators of all sizes and forms.

As a result the heat transmission was expressed in the following simplified formula:

$$W = F\,k\,(t_m - t_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where W = Total heat emission of the radiator in calories.
F = Heating surface in square meters.
k = Coefficient of heat transmission in calories per square meter per 1 deg. cent. per hour.
t_m = Average temperature of the heating medium in deg. cent.
t_i = Temperature at eye-height of the room to be heated in deg. cent.
$t_m - t_i$ = Temperature difference in deg. cent.

The value of the coefficient k varies with the temperature difference $(t_m - t_i)$, the nature of the heating surface, the velocity of air circulating through and about the radiator, as well as on its construction, height, number of sections, position in test room, etc.

In 1910 Dr. Dietz[2] developed the following general equation for heat transmission from Rietschel's experiments:

$$W = FC\,\frac{(t_m - t_i)^p}{E^q} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where p = 1.3 to 1.4 and q = 0.119.
$(t_m - t_i)$ = again the temperature difference.
E = Number of sections of the radiator.
C = Coefficient of transmission.

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[1] Bericht über das Ergebnis des Preisausschreibens, betreffend Wärmeabgabe von Heizkörpern, erstattet durch Geh. Reg. Rat Prof. Rietschel, *Gesundheits Ingenieur* (Ges. Ing.), Vol. 19, No. 20, 1896.
Report of the Results of the Competition Concerning the Heat Emission of Radiators, rendered by Geh. Reg. Rat Professor Rietschel.
Note: The *Gesundheits Ingenieur*, published by R. Oldenbourg, Berlin-München, a weekly, covers all phases of sanitation and hygiene, particularly heating and ventilation. It is the official organ of the Experimental Station of the Technical University of Berlin, and other engineering bodies.

[2] Die Ermittelung der Wärmeabgabe von Raumheizkörpern, von Ing. Ludw. Dietz, Berlin, *Gesundheits Ingenieur*, Vol. 33, No. 18, 1910.
The Determination of the Heat Emission of Radiators.
Paper presented at Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Buffalo, N. Y., January, 1926.

This new coefficient is independent of the temperature difference and of the number of sections, but depends on all the other factors given for formula (1) and is determined from actual tests for these conditions.

Rietschel published the results of his very complete series of tests with tables and transmission coefficients in the Leitfaden, First Edition, 1893.[3] This work was later translated into French from the Fourth German Edition by Leon Lasson and published in Paris, 1911, under the title of *Traité Théorique et Pratique De Chauffage*

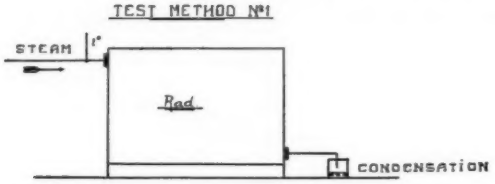

FIG. 1. STEAM RADIATOR ON CONDENSATION TEST

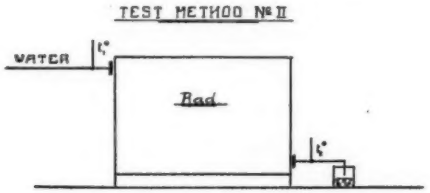

FIG. 2. WATER RADIATOR ON FLOW TEST

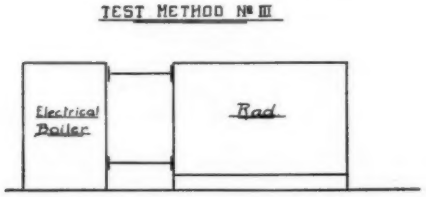

FIG. 3. STEAM OR WATER RADIATOR TESTED BY USE OF ELECTRIC BOILER

et De Ventilation. After the death of Prof. Rietschel the Sixth Edition of the Leitfaden was issued by the writer, and for this also the translation rights into French were assumed by the Librairie Polytechnique, Ch. Beranger, Paris.

In this manner Rietschel's investigations became a part of the technical literature of France as well as of Germany. Equation (1) was generally used in connection with the coefficients established by Rietschel. The results were also adopted in the heating practice of other countries, Austria, Belgium, the Balkans, Czecho-Slovakia, Holland, Hungary, Japan, Russia, Scandinavia, Spain and Switzerland,

[3] *Leitfaden zum Berechnen und Entwerfen von Lüftungs-und Heizungs-Anlagen*, von H. Rietschel. Verlag Julius Springer, Berlin, 1893.
Guide for the Calculation and Design of Heating and Ventilating Systems, by H. Rietschel.

wherever technical literature has become part of heating and ventilating engineering.

At a somewhat later date A. H. Barker and M. Kinoshita of the University College, London, conducted a series of tests on "Heat Transmission Coefficient of Radiators."[4] They found that the coefficient of transmission was proportional to

$$(t_m - t_i)^{1.3} \quad \ldots\ldots (3)$$

This agrees very well with equation (2) of Dietz.

In 1924 the *Forschungsheim für Wärmeschutz* in München, Bavaria, made a new series of heat transmission tests in which stress was laid on clearing up differences that had become apparent between the results of previous experiments. It followed that they used methods intentionally different from the conditions of actual practice, for example, the radiator to be tested was placed in the center of a large room as this gave more constant results.

The formula derived from these experiments as given by Dr. Schmidt[5] is:

$$W = \frac{FK(t_m - t_i)^{1.3}}{80} \quad \ldots\ldots (4)$$

This equation likewise is in agreement with formulas (1) and (2) presented by Dietz fifteen years earlier and the English investigators.

In the United States Allen, Willard, and other investigators (Carpenter, Barrow, Monroe) were very much interested in this problem. Their publications[6] list different tables of coefficients, which in view of American heating practice were derived from formula (1). Further simplifications have gone to the limit of using 240 B.t.u. per sq. ft. of direct steam radiation—three column 38-in. height—as the heat emission for figuring radiation.

From these references to a part of the extensive technical literature on heat transmission of radiators one would almost be justified in believing that there was sufficient international agreement in experimental results. But it has been the world-wide reputation of the United States of ever assuming new view points and making more practical application of science to industry. Mr. Frost in the JOURNAL OF THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS[7] has clearly indicated such an application.

> "Summarizing this subject, one is impressed that the present method of testing radiation by which only the condensation is measured is very incomplete, and that a new method must be developed, a method that will cover all three modes of heat transfer—radiation, conduction and convection—if all the data necessary to properly study the subject of heat transfer from radiation is to be secured.
>
> "Dean Allen was engaged upon this subject when his untimely death cut short its completion. Since then there have been no published reports on the subject, although there has been expressed from time to time a very emphatic sentiment for an improved method.

[4] Report by M. Kinoshita, Vol. XVIII, 1918–20, Institution of Heating and Ventilating Engineers, London. Tests conducted by the Dept. of Heating and Ventilation at the University College, London.

[5] Neue Untersuchungen über den Wärmebedarf von Gebaüden und die Wärmeabgabe von Heizkörpern. von Dr. Ing. Schmidt, München. *Ges. Ing.*, Vol. 47, No. 50, 1924. Paper presented at the XI Congress for Heating and Ventilation, Berlin, Sept. 1924.
New Experiments as to the Heat Requirements of Buildings and the Heat Emission of Radiators.

[6] Allen, *Heating and Ventilation;* Harding and Willard, *Heating and Ventilation;* A.S.H.&V.E. "PROPOSED CODE OF MINIMUM REQUIREMENTS FOR HEATING AND VENTILATION," Heating and Piping Contractors National Association, *Engineering Standards.*

[7] JOURNAL, A.S.H.&V.E. December 1924, p. 746. "Some Facts about Enclosed Radiation," presented at the Annual Meeting of the Society, Boston, January 1925.

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"Obviously any improved method must employ an insulated room or chamber in which all the energy emitted both above and below as well as within the range of sensible heat could be measured."

As we consider this idea more carefully and look back on previous investigations we note that three methods have been used. The first method (Fig. 1) measures the condensation of steam passed through a radiator. The second method (Fig. 2) measures the weight and temperature loss of the water flowing through a water radiator. The third method (Fig. 3) employs a small electrically heated boiler, supplying steam or water to the radiator to be tested, returning the condensate or water to the boiler; the heat emission and the heat lost from this boiler are accurately determined; then in a condition of equilibrium good results can be obtained. No other methods than these three are described in technical literature.

For such methods of tests the investigators assume as self-evident that each radiator is 100 per cent useful in room heating, that is the entire heat supplied to

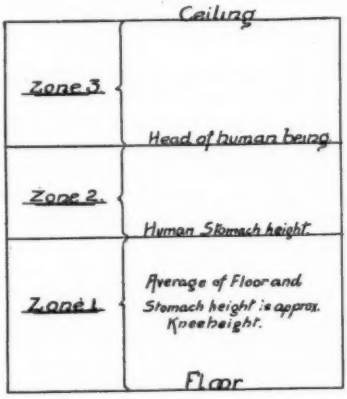


FIG. 4. HEAT ZONES IN A ROOM

it is usefully employed for the purposes of warming the occupants; that therefore the heat output being equal to the heat input, and the latter being measured, that the coefficient of heat transmission so calculated should be used for classifying radiators.

It is from this point that the new method must start. The assumed condition that a radiator is 100 per cent efficient in the above sense is not self-evident, on the contrary it is erroneous.

In preparing for such a change let us consider a somewhat parallel case in the field of illumination, where the new method won a complete victory. It was natural to assume in the case of the electric light that determination of the watt consumption would be a satisfactory measure of the lighting effect. But it was soon found that the input of current might be reduced and the lighting effect increased. Some adequate measure had to be found to protect the lighting industry and the public. Gradually standards, usually in the form of candlepower of particular specifications and intensity, based on photometry were adopted in many countries

and later expressed in the form of the international candle,[8] which gives a standard unit used throughout the civilized world for the technique of illumination.

A similar development must take place in heating science. If for instance radiators for steam were built merely as condensers, the methods used up to the present time would be sufficient. This is not the case, radiators should not be considered as condensers but as means for heating when placed in rooms for human habitation, to maintain as perfect hygienic living conditions as possible.

Hygiene itself, a subject extensively studied in institutions of learning in the United States, confirms the adage that we should have a cool head and warm feet. The reverse, a warm head and cold feet, is a sign of illness. A room that is warm

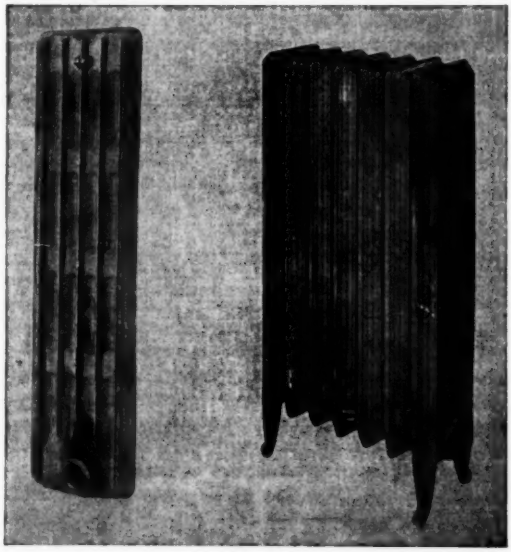


FIG. 5. FLUE RADIATOR

at knee height will always maintain sufficient warmth for the head (apart from cold draughts) but the contrary is not true.

Such fundamental rules were applied in ancient times, the Egyptians and Romans built hypocaustic heating systems, where heat was carried through ducts under the floors of the rooms to be heated. In their residences the Babylonians set up platforms for old people, knowing well that on these high seats they would be warmer and protected from cold floors.

The first rule that we can apply from this experience is to keep the floor warm. This may be done by using a material that withdraws the least amount of heat from the feet. As we all know a smooth stone floor is most uncomfortable and conditions are greatly improved by the use of non-conducting floor construction or covering.

In general practice the heating system does not directly warm the floor and should

[8] *Mechanical Engineers' Handbook*, Marks. *Illumination*, p. 1367–8.

therefore be directed to those parts of the human body, which are particularly susceptible to cold. This may be more clearly expressed by saying that the correct amount of heat should be supplied in the zone from the floor line to the waist line, that is at the height of the knee as a mean or average. If we divide a room as in Fig. 4, where Zone I extends up to the waist, Zone II up to the head, and Zone III to the ceiling, we can immediately say that most of the heat should be distributed satisfactorily and hygienically to Zone I; Zone II will require less heat; and excessive heat in Zone III is wasted.

It has been maintained that heat distributed to the ceiling, *i. e.*, in Zone III, is not lost, but helps to heat the floor above. There are several objections to this:

1. As a general rule the function of a radiator is to heat the room in which it is placed, not the one above it.

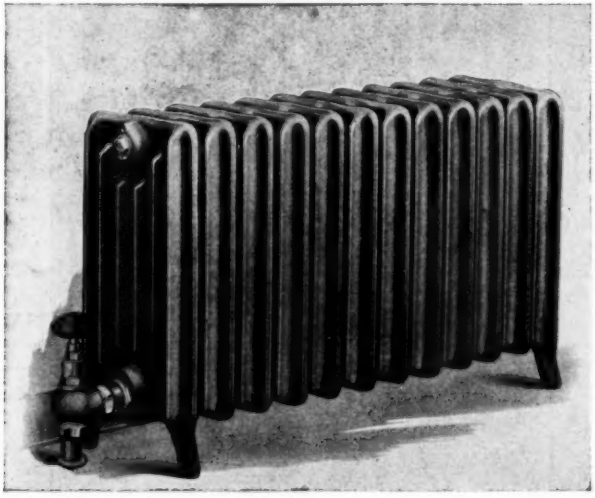


FIG. 6. WINDOW RADIATOR

2. In many cases rooms that are not to be heated, or that are temporarily unheated, are located above the room in question.

3. In other cases the spaces above the room heated are exposed so that heat streaming up to them is entirely wasted.

4. Heat losses from the room depend on the difference between inside and outside temperatures. A higher ceiling temperature therefore increases this heat loss.

5. Natural ventilation is created in any heated room. Warm air is dissipated from the upper part of the room into the atmosphere and cold air enters through infiltration at the windows and doors. Overheating in Zone III implies an increased heat loss by natural ventilation.

Therefore we say that in general the heat output of a radiator should be studied in relation to the room in which the radiator is set up, not to adjacent rooms; excessive heat on the ceiling is an additional heat loss.

Now we can clearly see that that radiator will be best in hygienic and scientific design, which transmits the greatest part of heat through Zone I. Therefore the efficiency of a radiator is not 100 per cent, but the ratio of the heat output in Zone I (knee height) to the entire input (condensation) of said radiator. As we are not able to find this ratio for the time being a relative or comparative method will allow us to take a step forward in the classification of radiators for practical use.

In the case cited for illumination, where difficulties due to many variations in the measurement of lighting effect were brought into order by the determination of a standard expressed in scientific terms, so in the heating trade a standard or standard form of measurement for heating effect will be a great aid in the problems of heat emission. Scientists, engineers, and the industry with the cooperation of the government or authorized societies should determine a standard radiator used under certain specified conditions. Such a standard radiator could be made up of entirely plain sections not designed for actual installation in practice but only for such comparative tests. Then the regular types or new designs of radiation should be tested and rated relative to this standard.

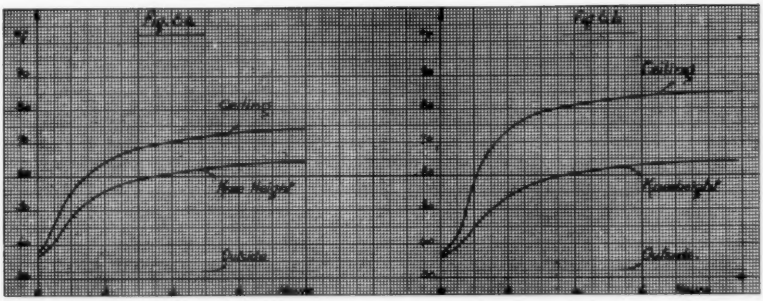


FIG. 6*a*. TEMPERATURE CHART OF WINDOW RADIATOR

FIG. 6*b*. TEMPERATURE CHART OF FLUE RADIATOR

The American Radiator Company working on these questions for two years has already taken the first step in this direction. Before considering in greater detail the method of comparative testing and rating of radiators, the manner of carrying out these tests, and some of the results obtained, an example will show the important nature of the questions suggested and answered by this method.

On the one hand consider a Peerless Flue Radiator (Fig. 5) 38 in. high with extended indirect rib heating surface, on the other hand a Peerless Window Radiator (Fig. 6) 20 in. high. Our tests give the following results:

Judging by condensation only, the Peerless Window has an emission 11 per cent less than the Peerless Flue. But judging by heating effect at knee height the Peerless Window is 17 per cent more efficient than the Flue radiator. We can therefore see how large an error, about 30 per cent, can be made in judging radiators by condensation only.

Let us take another example. Figs. 6*a* and 6*b* show the results obtained from two radiators tested in the test rooms, with equal heat losses and for the same outside temperatures. The knee height temperatures are the same, but in 6*a* the radiator gives a ceiling temperature of 75 deg. fahr., whereas the second radiator in 6*b* gives a ceiling temperature of 85 deg. fahr. The condensation of the radiator of Figure

6*b* was naturally higher than that of Figure 6*a*, but the occupants do not derive the benefit of this extra heat input and it is wasted, at the same time the operating cost for the second radiator must be higher. We again observe how the measurement of condensation only, gives an erroneous impression of what a radiator will actually do in heating a room for human habitation.

We shall now describe the experimental installation and method used by the American Radiator Company in their laboratory at Yonkers, N. Y.

Test Installation

Up to the present time the test installation has been completed only for steam radiators, but will later be extended to include water radiators.

Two rooms of equal size *A* and *B* (Fig. 7) were constructed according to general

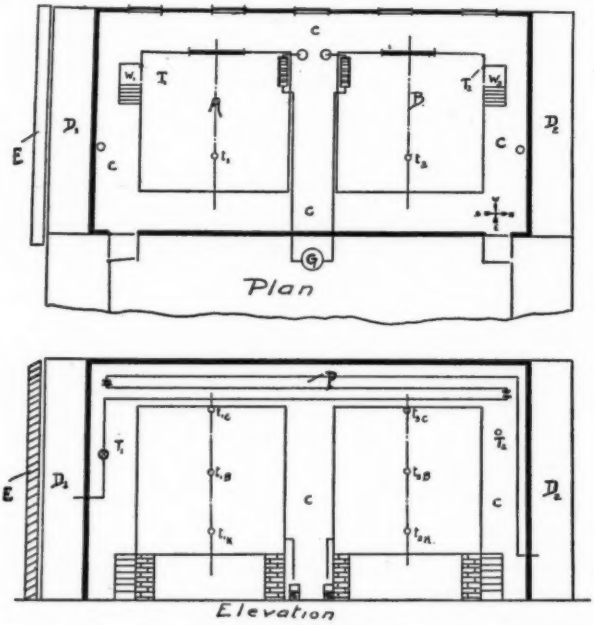


FIG. 7. TWO COMPARATIVE RADIATOR TEST ROOMS LOCATED IN A LARGE CHAMBER COOLED TO 32 DEG. FAHR.

American practice. The rooms are identical, supported on brick piers and with free space on all sides. (Walls are of 2 × 4 in. studding, covered on exterior with sheathing, building paper, metal lath and three coats of cement stucco. Walls on the interior are spruce lath and plaster. Floors are double, the surface of the floor being of oak. Ceilings are plastered similarly to the sides. The roof is covered with 1 × 6 in. sheathing and asphalt paper roll roofing. Each room has a single door, 2 ft. 8 in. × 6 ft. 8 in., also two single windows on one side, each 2 ft. 6 in. × 4 ft. 10 in., all of standard construction.)

As the drawing shows, these rooms are situated in a large surrounding chamber

C, which is completely insulated with cork and asbestos cement, and which stands free inside the laboratory proper, having air spaces D_1 and D_2 on all sides. This chamber C is cooled uniformly throughout by the coils P in the bunkers near the ceiling. The panel at E, painted aluminum bronze serves to keep out the sun's radiation. In fact these test rooms are so well protected that neither in summer nor winter are they affected by atmospheric disturbances. An even temperature is maintained inside C, by means of three electric fans, which give a slight air movement.

Fig. 8 shows the even temperature T_1 and T_2 maintained on both sides of chamber C automatically recorded by electric resistance thermometers. These are checked by a number of calibrated mercury thermometers.

Any slight inequality in the heat loss of the two rooms or in the steam supply to the radiators can be eliminated by an interchange of the radiators between the two rooms. A number of such interchanges were made both in summer and

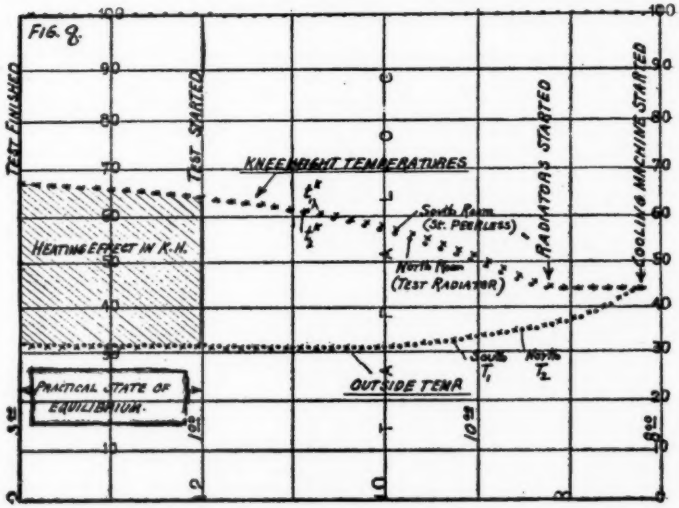


FIG. 8. TEMPERATURE DIAGRAM USING COMPARATIVE RADIATOR TEST METHOD

winter and showed that such inequalities were less than ±1 per cent. Furthermore as the standard radiator is always kept in room A and the radiator to be tested in room B, the relations of the latter to the standard are constant.

Steam is supplied from an automatically controlled gas boiler (Figs. 7 and 9) sufficiently superheated to enter the radiators with 1 deg. fahr. superheat. Water separators and traps are located in the supply lines at several points, also immediately before the radiators, to insure absolutely dry steam. Both the supply and condensation lines are well insulated. The inlet and outlet temperatures of the steam passing through the radiators are observed by calibrated thermometers inserted directly into the medium through special brass stuffing boxes.

Conforming to the demands of hygiene and the growing practice in this country

the radiators are placed as near as possible to the source of the greatest heat loss, the windows, and still permit of using higher models of radiators.

The room temperatures are measured at points t_1 and t_2 in the center line of the room (Fig. 7), one quarter of the distance from the rear wall, at three heights, knee height—18 in. from the floor (t_1k and t_2k), at breathing height—5 ft. from the floor (t_1b and t_2b) and just below the ceiling (t_1c and t_2c). These locations in the rooms were adopted after experimentation as being the least disturbed directly by influences from the windows and doors. The temperatures at knee height t_1k and t_2k are also recorded with those of the outer room (Fig 8). The readings in the rooms are taken every half hour and serve as a check on the instrument records.

Photograph (Fig. 9) shows the automatically controlled gas boiler, the tank, distribution of steam lines, recording instrument and some of the traps. Fig. 10 shows an exterior view of the two test rooms, supply lines to the radiators, thermometer and electric wiring. Fig. 11 shows an inside view of one of the two identical test rooms with the standard Peerless Radiator set up.

A test is run somewhat as follows:

8:00 A.M. Doors of test rooms have been open over night to permit of ventilation.
The test rooms are now closed.
The cooling system is started.

8:30 A.M. The steam boiler is started.

1:00 P.M. The test installation is so figured that by this time the temperatures in the cooling chamber will be about 32 deg. fahr. and inside the rooms at knee height about 65 deg. fahr.
A condition of practical equilibrium is attained in both rooms at this time, control readings are taken and a two-hour test period starts.

The sample diagram Fig. 8 shows the records of the test.

The heating surfaces of both radiators in the test rooms are taken so that in a condition of equilibrium the temperatures at knee height will be the same.

It has been maintained that the measurement of temperatures for rooms such as these can only be given correctly by thermometers protected against radiation, *i. e.*, with a bulb gilded. We do not agree with this opinion. The human body enjoys the benefits of heating in the form of radiation, conduction and convection, therefore instruments should be used that react to all three, which up to the present time are ordinary thermometers, either glass or resistance with a normal outer surface.

The comfort of human beings is not only dependent on the temperature of the air, but also upon the relative humidity. In order not to complicate further the records of the tests, they are started and finished with the same temperatures and relative humidities in both rooms (knee height). As a check the relative humidity was observed at various times and showed differences of not more than ± 1 per cent.

While recent publications of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS[9] show that air motion is important for the comfort of human beings, instruments in the two test rooms do not indicate sufficient air motion where the temperatures are measured to consider this factor. It should be noted, however, that application of the records for the test rooms to the Psychometric Charts of the

[9] JOURNAL, A.S.H.&V.E. January 1925. "Effective Temperature with Clothing," presented at Annual Meeting, Boston, 1925.
GUIDE, 1924–25, A.S.H.&V.E. Chapter XVIII. "How Temperature, Humidity and Air Motion Affect Human Comfort."

A.S.H.&V.E. indicate that the conditions maintained in the rooms are well within the Comfort Zone.

Professor Barker of London believes that the thermometer reading is not a true index of the feeling of warmth, which depending on the rate of heat loss can only be measured by an instrument calorimetric and not thermometric in principle.

He has constructed an instrument consisting of three mercury thermometers of identical dimensions and having large spherical bulbs of which No. 1 is covered with lampblack, No. 2 with silver and No. 3 with moistened muslin, and all graduated

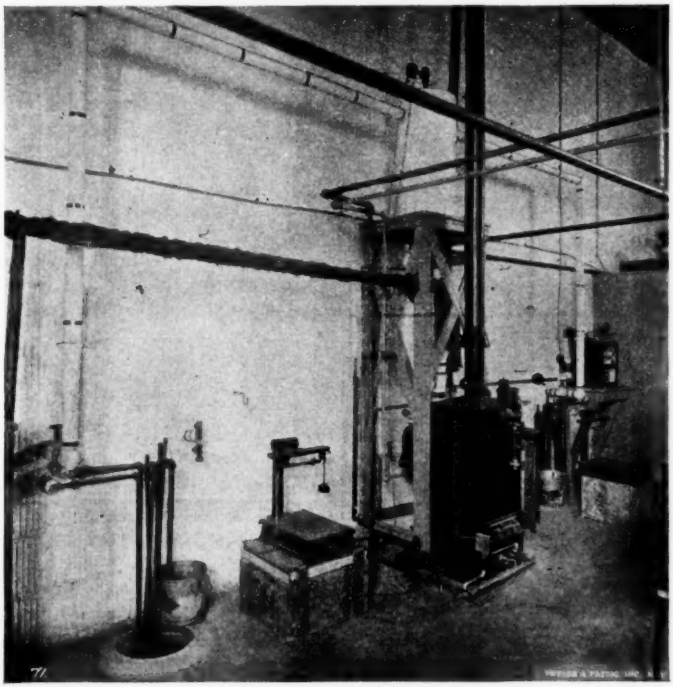


FIG. 9. GAS BOILER (AUTOMATICALLY CONTROLLED), STEAM TANK, STEAM DISTRIBUTION LINES RECORDING INSTRUMENT, TRAPS, SCALES

between 90 deg. fahr. and 110 deg. fahr. and suspended side by side. Previous to taking an observation all the three are warmed beyond the upper limit and allowed to cool gradually. The time required in each case to fall between 100 deg. and 95 deg. fahr. is taken by a stop watch. The difference between these observed times of cooling of Nos. 1 and 2 is a measure of the net intensity of radiation, while the difference between the cooling times of Nos. 2 and 3 is a measure of the heat loss due to evaporation and radiation together.

The same experimenter has also proposed a variation of this method in which small electrically heated and insulated resistances are fused into the bulbs. The

power in watts necessary in each case to maintain the bulbs at body temperature is observed by a wattmeter or ammeter suitably graduated and gives an accurate measure of the heat lost (1) by convection and radiation, (2) by convection only, (3) by convection, radiation and evaporation. These instruments are not yet on the market. See also A. H. Barker's discussion.

Results of Tests

One of the first and most important factors to be considered when calculating

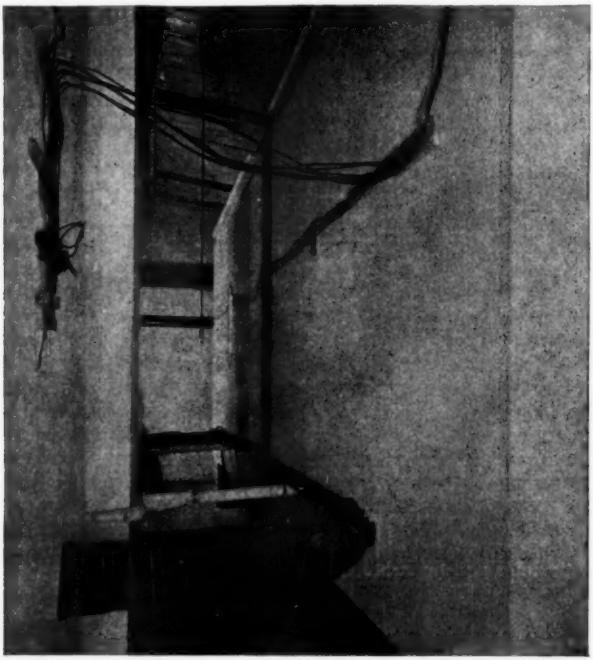


FIG. 10. EXTERIOR VIEW—TWO TEST ROOMS—RADIATOR SUPPLY LINES, THERMOMETERS, WIRING OF THERMOELEMENTS

and estimating the results of the tests is, as mentioned earlier, that all such results must not be considered in an absolute sense, but relative to a standard.

As noted for the technique of illumination a standard was fixed and various lighting factors judged in relation to it. For such a standard in these comparative tests we have used the Peerless three-column 38 in. height, which is so generally used throughout the country and is satisfactory in its heat emission. Theoretically the latter does not matter, as this radiation is only used as the norm from which the deviations of other radiators are recorded.

After studying different methods of computing the results the following was found to be the simplest and the most logical in every way. Based on the point clearly emphasized earlier in this article, that from an hygienic view point a room

should have a comfortable temperature at knee height, the size of the test radiator has been selected so that the knee height temperatures recorded in both rooms are equal in a state of equilibrium. Then we can say that both radiators have the same heating effect. That is to say, a certain number of sections of the test radiator as installed are equivalent in heating effect to a fixed number of sections of the standard radiator. Knowing the heat emission of the standard radiator and its surface we can calculate the heating effect and rating per section of the test radiator, as shown in the computations given below. Where any slight difference is indicated in the knee height temperatures a correction can be made easily. As already mentioned the humidity and the air motion in both rooms are practically

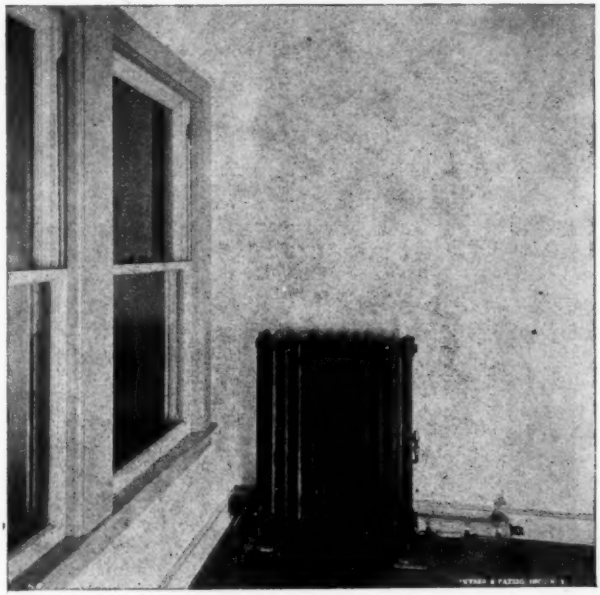


FIG. 11. INSIDE VIEW OF ONE OF THE TEST ROOMS WITH STANDARD SET-UP. (DISREGARD REFLECTION OF RADIATOR IN WINDOW PANE.)

the same, which reduces the very complicate calorimetric problem to a thermometric one and permits the use of thermometers instead of calorimetric instruments (Katathermometer).

In order to have tests standardized, uniform conditions should be maintained throughout, in this case an outside temperature of 32 deg. fahr. (equivalent to zero weather for normal winter exposure) and 65 deg. fahr. inside temperatures at knee height. The percentage of error for these tests is within the limits of ± 2 per cent, which is sufficient for all practical purposes.

Determining Radiator Values

Since this new method of comparative tests gives us the heating effect of radiators

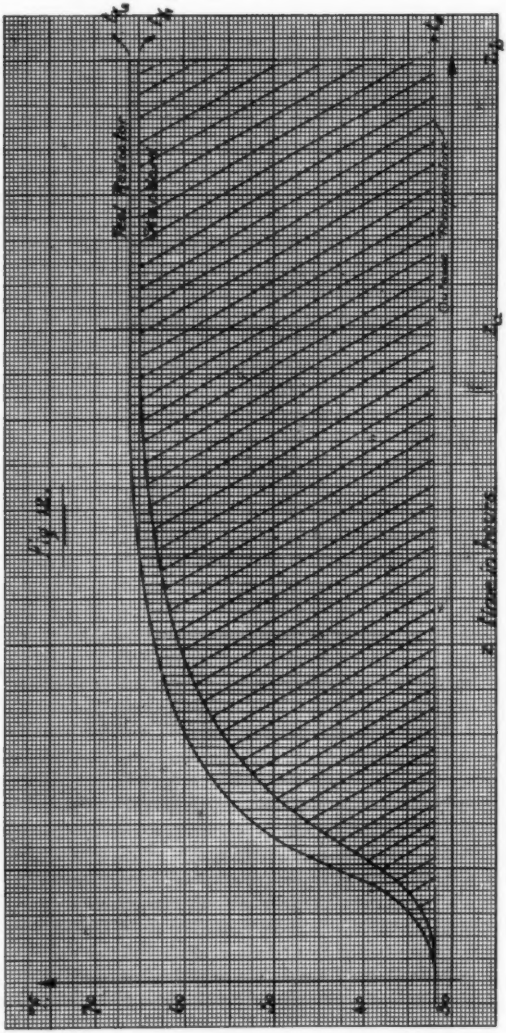


FIG. 12. KNEE HEIGHT TEMPERATURE DIAGRAM

under conditions closer to those obtaining in practice than heretofore, let us see how it can be applied.

One procedure would be for an independent laboratory under the direction of recognized authorities to test all radiators under standard conditions and in standard test rooms, in the manner which has just been outlined, and to publish the results in the form of tables.

The objection might be raised that relative values for radiators tested in these

two rooms of equal heat loss would not hold for other rooms. This might be true for very exceptional cases, but for the great majority of practical installations the relative results obtained from a set of standard rooms can be taken as an excellent criterion for classifying radiators within the limits of ±2 per cent of this method.

For example, tests conducted at the Technical University of Berlin,[10] were carried on under very similar conditions by the comparative method. In the first instance the heaters were placed in two rooms (750 cu. ft. each) of equal heat loss below the ground and without windows. The stoves were then brought into two other rooms (1800 cu. ft. each) on the first floor with windows and normal surroundings and equal heat loss, under different conditions of temperature humidity and wind observations, the relative results classifying the heaters checked within the limits of ±2 per cent error.

Computation of Test Results

The following examples will show how in a simple and logical manner the results of the test are expressed in a form directly applicable to the best engineering practice.

The standard radiator in these tests was rated at 5.00 Standard units per section and from actual measurements it was found that each Standard unit (St. u.) emitted 240 B.t.u. per hour. This value is also in accord with boiler manufacturer ratings, a very important and practical coincidence, as boilers and radiators should be rated in units of equivalent value.

Example I

As shown in the test record sheet (Fig. 8) when the knee height temperatures in both rooms are equal, we have

$$R_1 = \frac{a}{n} \times R \qquad (5)$$

where R_1 = Rating of the radiator tested in standard units (St.u.).
R = Standard units of the standard radiator = 5.00 St.u.
a = Number of sections of standard radiator.
n = Number of sections of radiator tested.
r = Actual heating surface of radiator tested in square feet per section.

then with

R = 5.00 St.u. at 240 B.t.u.
a = 8 sections.
n = 7 sections.
r = 5.4 sq. ft.

$$R_1 = \frac{8}{7} \times 5.0 = 5.72 \text{ St.u. (Standard units)}$$

$$\text{Effective B.t.u. per section} = 5.72 \times 240 = 1375 \text{ B.t.u./hr.}$$

$$\text{Effective Coefficient} = \frac{1375}{r} = \frac{1375}{5.4} = 255 \text{ B.t.u./hr. per actual sq. ft.}$$

[10] Beihefte zum *Ges. Ing.*, Nos. 13 and 14, "Results of Comparative Tests on Tile Stoves." Supplements to the *Gesundheits Ingenieur*.
Mitteilung 29 and 32, "Prüfungsanstalt für Heizungs-und Lüftungseinrichtungen der Kgl. Technischen Hochschule zu Berlin," R. Oldenbourg, München, 1920–21.
Bulletins 29 and 32, "Experimental Station for Heating and Ventilation," Installations of the Royal Technical College at Berlin.

Example II

When the knee height temperatures are not equal as shown in Fig. 12, a correction factor f must be used, where

$$f = f_1 \times f_2 \quad \ldots\ldots(6)$$

f_1 is the integral of the 1.3 power of the relation of the temperature areas, cross-hatched in Fig. 12, which can be expressed mathematically as

$$f_1 = \int_{Z_1}^{Z_2} \left[\frac{(t_{2k} - t_o)^{1.3}}{(t_{1k} - t_o)^{1.3}} + F \right] dz \quad \ldots\ldots(7)$$

the integral taken for any desired part of the test period. F represents the influence of the storing up of heat in the walls, etc. The exponent 1.3 of formula (3) is sufficiently exact for this correction within the limits of the test accuracy.

As in our practice only the period of test when in a steady state is taken, lasting from time Z_a to Z_b, then equation (7) will be simplified to

$$f_1 = \frac{(\text{aver.})\ (t_{2k} - t_o)^{1.3}}{(\text{aver.})\ (t_{1k} - t_o)^{1.3}} \Bigg|_{Z_a}^{Z_b} \quad \ldots\ldots(8)$$

where (aver.)$(t_{2k} - t_o)$ represents the average difference between temperature in knee height and outside temperature for room B, and (aver.)$(t_{1k} - t_o)$ the average difference between temperature in knee height and outside temperature for room A (Fig. 7).

f_2 is derived from equation (3) and is expressed as follows:

$$f_2 = \left[\frac{(t_d - \text{aver. } t_{1k})}{(t_d - \text{aver. } t_{2k})} \right]^{1.3} \quad \ldots\ldots(9)$$

where t_d is the average steam temperature, which is the same for both radiators (aver. t_{1k}) and (aver. t_{2k}) are calculated for the time interval $(Z_b - Z_a)$.

As an example for the test shown in Fig. 12 we obtain:

$$f_1 = \frac{(66 - 32)^{1.3}}{(65 - 32)^{1.3}} = 1.039$$

$$f_2 = \left[\frac{212 - 65}{212 - 66} \right]^{1.3} = 1.009$$

$$f = 1.039 \times 1.009 = 1.05 \text{ Correction Factor.}$$

Taking the values in Example I we obtain:

Rating R	$= 5.72 \times 1.05 =$	6.00 St.u. per section.
Effective B.t.u. per section	$= 1375 \times 1.05 =$	1445 B.t.u. per section/hr.
Effective Coefficient	$= 255 \times 1.05 =$	268 B.t.u. per sq. ft./hr.

As the correction is comparatively small a large error in the actual figures is unlikely to occur.

f_2 in most cases, as has been verified by our tests, is very small and can therefore be neglected for practical purposes.

As we see, it is not necessary for the purposes of the tests to observe the condensation of the test radiator. But it is taken for other reasons (dimensions of pipes, boiler load, operating expenses, etc.,) as soon as the "steady state" is practically reached.

One more point should be brought out. As can be seen from Fig. 12 it was found that radiators with a high "Effective B.t.u." heat up the room more rapidly

than the standard. When measurements are made by condensation such facts are not at all apparent, an added advantage for the comparative method.

In considering the question of the size of the radiators, we can safely state that for radiators of from six to twenty sections the total effective B.t.u. is obtained by simply multiplying the number of sections by the "Effective B.t.u. per section" within practical limits of ± 2 per cent.

This does not apply to radiators with less than 6 sections, because in such cases the effective B.t.u. increases rapidly.

General

For the time being this method of determining the heating value of radiators is not only desirable but essential for correct design and judgment. We do not require a certain number of square feet of iron surface in our rooms, but a definite amount of heat properly distributed at knee height. Anyone familiar with standard radiator designs can easily construct a radiator with a large heating surface, but a comparatively small effective heat output at knee height.

The only method for checking excessive statements has been the determination of condensation coefficients, which are not the right basis for measurement according to the facts already presented. It is more satisfactory to make the tests as described and thereby determine the rating or effective heat output of radiator at knee height.

When radiators are installed on the basis of their "Effective B.t.u.'s" as determined from this new method of test, their heating effect will be applied most economically for the engineer and builder and most hygienically and to the greatest satisfaction of the occupant.

It may be worth while to mention that the idea of Practical Tests under Standard Conditions can be applied to the problem of Boiler Rating simplifying the whole matter a great deal.

DISCUSSION

(WRITTEN): I have had the privilege of reading this paper in its preliminary draft, and of discussing it personally with Dr. Brabbée.

The Doctor has asked me to prepare a brief statement of my own view point. I only regret that my necessary return to Europe prevents me from discussing it with the Society of which I am proud to be a member.

The essense of the paper is based on two theses:

(1) That a practical comparison between the heating effect of the radiator under test and that of the standard one in a standard room, is a better measure of its value as a means of heating than an absolute test of the total emission.

(2) That a better criterion of the useful performance of any radiator in a room is the effect produced at knee height rather than as usually observed at head height.

With these I am in complete agreement, as well as with the substance of the paper as a whole. I think that this method of testing radiators should be provisionally adopted for rating them until some more complete method can be established.

The new method is of course an empirical one. The progress of any science always results in replacing empirical methods by analytical ones. This method is therefore only a step, but a very useful one, towards the completion of the investigation. The analytical investigation will certainly be so difficult and protracted

that we cannot wait for its completion before removing the present chaotic condition of things in which everyone seems to rate radiators according to his own personal fancy. The one point in the empirical method which Dr. Brabbée describes and with which I do not altogether agree, is the use of the thermometer as a criterion of the comfort of the conditions produced. I do not believe that the heat conditions of a room can be measured satisfactorily by any instrument which is thermometric in principle, but that the only possible instrument which can measure with precision such a complex function as human heat comfort must be calorimetric in principle. Assuming that the heat comfort of the human body depends upon the rate of heat loss in various ways, by convection, radiation and evaporation, I cannot conceive that any instrument which does not in some way or other measure heat loss in all these ways can possibly be directly applicable to this very complex problem.

I am not prepared at this moment, however, to propose with confidence any instrument to replace the thermometer at the present stage of knowledge, and which can be easily applied. As Dr. Brabbée mentioned in the paper, I made many years ago an instrument which I believe will serve the purpose, but it has not yet been tested out. If it is successful, the only difference it would make in the application of Dr. Brabbée's empirical method would be the substitution of the new instrument for the thermometer, the experiment being otherwise the same as Dr. Brabbée proposes.

I should like to take advantage of the present opportunity to explain my view point as to the future or analytical investigation on which we are now engaged in England. We are very anxious to proceed in all such matters in complete agreement with yourselves, and not to duplicate the work unnecessarily. We have now in draft and are about to publish a complete bulletin giving the results up to date of our own researches on radiators, which include the accurate determination of heat losses from water radiators at all temperatures, by which of course I mean the total output or input. This we regard as the first and fundamental step of the investigation, because whether or not this is a criterion of the effectiveness of the radiator for room warming, and however the latter is to be measured, it is certainly the function which determines the boiler power necessary and is a necessary figure or element in the determination of the scientific efficiency of the radiator itself—however, that elusive term may be defined.

My view point as to the future progress of the analytical investigation is as follows:

It appears self evident to me that if there are two radiators of which the total output is the same, and if that output is similarly subdivided in each case both as to amount and direction between convection and radiation, then the heating effect on any room whether measured by thermometer at knee height or in any other way, must be identical. In other words, the essential things which we require to know about the radiator itself, and apart from its effect on any particular room, are the amounts both of the convected and the radiated heat and the way in which these are distributed. The effect of any particular distribution on any particular room is a problem to itself, even more complex than the emission from a radiator.

I regard the room as producing negative emission which requires investigation on exactly the same principle as the positive emission from the radiator. The radiator is to be regarded in my view as a positive emitter or negative absorber while the room is generally a negative emitter or positive absorber. The emission from the radiator and the absorption by the room are complementary phenomena. The

effect on the room is the resultant of these two influences of which one is as important as the other. It would be a mistake, therefore, to regard individual experiments described in this paper solely as a test of the radiator. They are equally a test of the experimental room in which they are conducted. At this point I diverge from Dr. Brabbée's view on a matter of theory which does not affect my opinion of the experiments as a whole. I do not consider that the temperature effect measured at knee height can be absolutely determined irrespective of the thermal properties and the dimensions of the room.

Dr. Brabbée eliminates this question for experimental comparison by constructing two identical rooms and using the results of the experiments for a comparison between two different radiators and not as a test of the radiator in an absolute sense. He believes that the heat properties of the room can be neglected for the great majority of practical installations. I also believe this is probably true and agree that in the great majority of ordinary rooms the similarities of construction and shape are such that the point is not of importance and that therefore for practical purposes the experiments as proposed will usually give a reliable idea of relative values pending the completion of the investigation.

We are now engaged in London in investigating the output of radiators by convection and radiation and in obtaining polar curves showing the intensity of the interchange of radiation in all directions over a complete hemisphere surrounding the radiator as its center, the readings being taken on an absorbent surface having a standard emissivity and maintained at a particular standard temperature. In regard to the effect on the room, my view is that precisely similar information is necessary about the room interior before we can claim to understand the problem of heating. These results will be and must be extremely complicated, but given the results of this investigation from both sides, the negative and positive, we should then be able to determine without any other information what the effect would be of any particular radiator in any room at knee height or any other height in any kind of environment. In that case and only in that case the empirical investigation of the heating effect on one particular environment, would be unnecessary. At present we have not that information and the nearest approach to it that we can look for at present would be obtained by Dr. Brabbée's method.

This is my point of view in regard to future developments as far as the relation between the radiator and the room is concerned. There remains a still further problem yet more complex, which has to do with the effect of any particular thermal conditions on the feelings of a human being, and this problem must be attacked in cooperation with the authorities on experimental hygiene. We have also very definite ideas on this subject which we are carrying out as rapidly as funds will permit. I shall keep in close touch with Dr. Brabbée and your experimenters on this side so as to make the rate of progress as rapid as possible.

DR. C. W. BRABBÉE: I was born in Vienna, Austria, educated in France and Germany, and I have been in this great and wonderful country only $2^1/_2$ years. You have made me, not only a regular member, but also a member of the Advisory Committee on radiation. May I take this opportunity to thank you very deeply and to tell you how proud I am of this honor.

Today I have the pleasure to introduce my paper, "The Heating Effect of Radiators"—a pleasure for me, but I hardly think for you, because my English is poor and I have great difficulty in making myself understood clearly. However, I think you have read my paper and, therefore, I can restrict myself to a short explanation.

I stated in my paper that we should not judge radiators according to their actual heating surface. We do not want a certain amount of iron in our homes, but a certain quantity of heat.

Everybody familiar with radiator designs, and I have been in this business about 25 years, can develop a radiator with a very large heating surface, therefore, a very good price, but a comparatively small heat output. These facts are proved by a large number of tests here and abroad.

I furthermore mentioned in my paper that the condensation of a radiator is also not a true measurement of its useful heat output. This is somewhat harder to understand, but anyway let's try to do it. Maybe the simplest way to explain it is to take a practical example. Here are two rooms of the same general conditions, especially of the same heat loss. (See Fig. 7, p. 509, November, 1925 JOURNAL.) Both rooms are located in one large room in which the temperature is always 32 deg. fahr.

We put in one room a heater acting mainly by radiation, heating comfortably the lower parts of the room in which we live. In the other room we place a heater acting mainly by convection—the hot air going to the ceiling according to the laws of gravity. Therefore, the lower parts of the room will be comparatively cooler, even if the condensation of this radiator will be higher than the first one.

Let us further assume that women, clever housewives as they are, enter those rooms and you explain to these ladies that the radiator in the right room has more condensation than the one in the left room and you ask "What do you think about these two radiators?"

I am sure the ladies will answer—"We do not understand anything about condensation, and we do not care about condensation at all, but we feel comfortable in the first room with warm feet, and we feel chilly in the second room with less heat in the lower areas. We are not flies living on the ceiling, but we want to have cool heads and warm feet."

Here you are—and because I think that women are very often right, I adopted their judgment for my method of testing radiators.

We put one radiator—its design doesn't matter at all—in one room and called it a Standard—and we compare with this Standard all other radiators, not for condensation only, but for heat output in the lower parts of the room which we call useful heat.

There remains one remark only. We know very well that the problem of human comfort is difficult and temperature, humidity and air motion play important parts. Attempts were made to measure human comfort by using a Kata thermometer instead of dry-bulb and wet-bulb thermometers making the problem complicated and difficult.

To simplify the matter we made the relative humidity equal in both rooms and we have practically no air motion. In doing this we reduced the complicated calorimetric problem to a simple thermometrical one in which we can use thermometers instead of Kata thermometers.

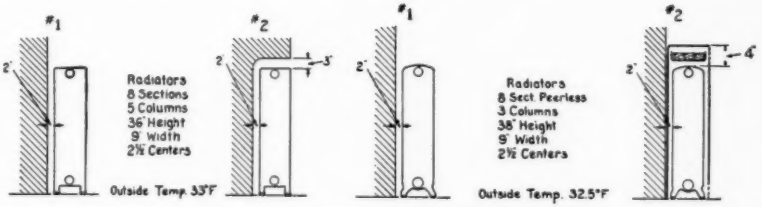
As far as we see the new method was received favorably, and we were asked for more information. We conducted about 150 tests and I can give you today some of our results.

We took absolutely equal radiators and set in one room the radiator free and the other in a niche (see Fig. A). You will see the condensation of the radiator in the recess is about 10 per cent less. You would say "the radiator is 10 per cent

less efficient"—but we have in both rooms the same temperature in knee height, about the same temperature in eye height, therefore about the same comfort for humans. Mathematically we see that the rating at "useful heat" is equal. Only the flies would not be satisfied. We see the ceiling temperature with the recessed radiator is about 5 deg. lower than in the other room.

The open radiator wastes 10 per cent of steam without any value for its own room. Maybe the next floor may profit by this 10 per cent, but as stated in my paper, we should consider the room in which the radiator stands only, and not rooms left or right, below or above.

In Fig. B there is one radiator in the open and an exactly equal radiator in an enclosure with a water pan. The condensation is 20 per cent less, also the useful heat—both checking in this case. The humidifying effect of the water pan is



Radiator #	Heat Surf. sq ft.	Condens. lbs/hr	Rated at 240 Btu Condensation sq ft.	Rated at 240 Btu Useful Heat sq ft	Room Temp. Knee H. °F	Room Temp. Eye H. °F	Room Temp. Ceiling H. °F
1 free	42.0	9.60	5.9	5.9	64.5	77.2	86.0
2 open niche	42.0	8.60	5.3	5.9	64.7	76.7	81.0
		-~10%	-~10%	-0%			

FIG. A.

Radiator #	Heat Surf. sq ft.	Condensation lbs/hr	Rated at 240 Btu Condensation sq ft	Rated at 240 Btu Useful Heat sq ft	Average Room Temp. °F	Average Room rel Hum %
1 free		9.6	5.06	5.06	69.7	37
2 with Enc. & Water Pan		8.0	4.02	3.96	66.3	44
		-~20%	-~20%	-~20%		

43.7%

FIG. B.

zero—the relative humidity in both rooms, taken for the same temperature, is practically equal.

Fig. C shows the results with normal four column peerless radiation 38 in. in height. Catalog rating, condensation rating and useful heat rating are practically the same, but in the lower heights the rating at useful heat is about 17 per cent greater than the catalog or condensation rating. This checks very well with the general practical experience that low radiators give much better comfort than higher ones.

We see exactly the same influence on three column radiators with the useful heat up to 19 per cent in favor of the lower heights.

In Fig. D, again, the same results show for the two column and one column radiators, where the lower heights are up to 21 per cent better in useful heat than catalog or condensation rating. These results again check our practical experience namely, that single column radiators, and especially the lower heights, give much better comfort than the normal rating indicates.

We see in Fig. E the same picture with wall radiators and especially window radiators with useful heat outputs about 20 per cent higher than the condensation

or catalog figures. It is a fact that window radiators always prove to be highly satisfactory for human comfort.

Some funny results will be seen in Fig. F. The radiator *X* with a catalog heating surface of 8.0 sq. ft. has a useful heat rating of only 4.47 sq. ft. and the radiator *Y*, with a condensation rating of 8.04 sq. ft. has a useful heat rating of 9.55 sq. ft.

An explanation for this interesting result can be found in the fact that with radiator *Y* we find only 6.3 deg. fahr. difference between the temperatures in

Radiator	Height	Heating Surf. Catalog	Rating at 240 Btu. Condensation	Useful Heat	Difference
	inches	sq. ft	sq. ft	sq. ft.	%
Peerless Three Column	45	6.0	6.30	6.42	+ 1.9
	38	5.0	5.06	5.06	± 0
	32	4.5	4.68	4.96	+ 6.0
	26	3.75	3.61	4.01	+11.0
	22	3.0	2.95	3.36	+14.0
	18	2.25	2.26	2.63	+16.4
Peerless Four Column	45	10.0	9.16	9.60	+ 4.8
	38	8.0	7.82	7.81	± 0
	32	6.5	6.36	6.70	+ 5.4
	26	5.0	4.90	5.45	+11.2
	22	4.0	3.69	4.25	+15.5
	18	3.0	3.01	3.52	+17.0

Radiator	Height	Heating Surf. Catalog	Rating at 240 Btu. Condensation	Useful Heat	Difference
	inches	sq. ft	sq. ft	sq. ft.	%
Peerless Single Column	38	3.0	2.96	3.20	+ 8.0
	32	2.5	2.46	2.77	+13.0
	26	2.0	2.00	2.36	+18.0
	23	1.67	1.80	2.15	+19.5
	20	1.5	1.56	1.89	+21.0
Peerless Two Column	38	4.0	4.02	4.20	+ 4.5
	32	3.33	3.28	3.58	+ 7.5
	26	2.67	2.60	2.95	+13.5
	23	2.33	2.30	2.68	+16.0
	20	2.0	2.02	2.40	+19.0

Radiator	Height	Heating Surf. Catalog	Rating at 240 Btu. Condensation	Useful Heat	Difference
	inches	sq. ft	sq. ft	sq. ft.	%
Peerless Window	20	5.0	4.92	5.77	+17.3
	18	4.5	4.52	5.28	+16.8
	16	3.75	4.03	4.69	+16.4
	13	3.0	3.16	3.78	+19.6
Peerless Wall	13⅝	7.0	8.05	8.63	+ 7.3

Radiator	Height	Heating Surface Actual	Heating Surface Catalog	Rating at 240 Btu. Condensation	Rating at 240 Btu. Useful Heat
	inches	sq. ft	sq. ft.	sq. ft.	sq. ft.
X	39	5.46	8.0	4.66	4.47
Y	12	8.35	8.5	8.04	9.55

+19%

	Temperatures °F Knee Height	Ceiling	Diff.
Y	66.5°	72.8°	6.3
X	64.3°	82.9°	18.6

UPPER—FIG. C.
LOWER—FIG. E.

UPPER —FIG. D.
LOWER—FIG. F.

knee height and ceiling—whereas the radiator *X* shows a difference of 18.6 deg. fahr., indicating that a lot of heat and steam is wasted in this case.

Before I close I would like to correct my paper in a certain sense. We stated that at present there are three methods of testing radiators. This is not entirely correct. There is a fourth method used about 15 years ago in Switzerland. The radiator was put in an air tight test equipment with entrance and exit and the radiator effect calculated by measuring the air quantity and increase of temperature. This method gave wrong results and was abandoned in a short time. Therefore, we did not mention it in our paper, but this method may have something to do with the discussion.

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May I close with the assurance that the American Radiator Co. and I will be only too glad to do everything that could contribute to the progress of our great Society.

T. M. DUGAN: I would ask Dr. Brabbée if it is possible that his scheme of rating on radiators would apply to boilers?

W. H. CARRIER: Dr. Brabbée has made reference to the use of the Kata thermometer and expressed a doubt as to its usefulness. I want to concur in this and add another thing in connection therewith if it is considered to be applicable to the paper; and that is that the Kata thermometer, which was supposed to indicate human comfort by Dr. Hill of England, does not indicate human comfort much more effectively than the dry-bulb thermometer. Neither of them are true indicators of comfort. This question was brought up and I thought it ought to be called to the attention of the meeting that the Kata thermometer was not an indicator of effective temperature as many of us supposed. The Kata thermometer indicates practically no more than a wet-bulb thermometer. It indicates it in an entirely different way but you would obtain the same result from wet-bulb readings in still air. The dry-bulb Kata can be calculated from the dry-bulb with the exception of velocity. The velocity of the air is the only thing that it takes into account accurately. The Research Bureau went into this very exhaustively and I would like to refer Dr. Brabbée and others who have not read these results to these papers which show conclusively the physical laws of the Kata thermometer and show that the comfort lines as determined experimentally are in no way indicated by the results of the Kata thermometer. The Kata thermometer cannot be used in any way as a measure of comfort. The only use that they have found for it is in the measurement of exceedingly low velocities, although they could also be measured by the hot wire anemometer.

THORNTON LEWIS: There was one thing the speaker touched on that I think is very important and from now on I believe we are going to pay a great deal more attention to it in heating and that is the difference in temperature from the floor up to the ceiling. Some recent experiments that we have been making in which the air was circulated indicate an absolute confirmation of just what has been shown by this paper relative to the quantity of heat required to give relative heat comfort. So much so that I can say that in a number of cases 15 per cent of the fuel used could be saved with the same relative heat comfort if that heat had been properly applied.

That is very well illustrated by the slide shown of the concealed or partly concealed radiator in the niche and the one standing in the open. Of course, I am in the controlled air business and would naturally look for this feature, but I was impressed by his sketch because at the top of the radiator he has really a nozzle and as that heat comes out the top of that niche or the lower part of the niche, which is at the top of the radiator, it helps to form a baffle to throw the heat out and across the room rather than allowing the heat to go up vertically.

This work has assumed in our minds such importance that we are preparing to present at an early date a paper before this Society that will bring out these ideas more forcibly than I have expressed them and I hope in a rather novel way. But so far as direct radiation is concerned I would say that the general underlying laws are absolutely confirmed by the experiments that we have made.

J. A. DONNELLY: I would like to ask Dr. Brabbée if he expects to make any tests on pipe coil radiation at the ceiling level or practically the ceiling level, and also encircling or partly encircling portions of the room at low heights. Also,

whether he expects to make any tests by the partial heating of radiators either by thermostatic control or by throttling the radiators with lower temperature differences between the inside and outside of his test room.

I find that in the latter case we do get less temperature differences between floor and ceiling and that as a matter of fact though this radiator is twenty per cent more efficient at maximum heating, considerably more is lost by overheating and the natural sequence of real economy in maintaining building temperatures would come in some method of cutting down this radiation as the outside temperature is not so severe. The two things might well be considered together.

DR. BRABBÉE: The first question concerns boiler rating. In these radiator tests I tried to depart from imaginary facts. The whole trouble with our boiler rating is that we have no basic facts; everybody does as he wants to. If we could attach the boiler rating to something given, it would be a lot better. I have in mind to express the rating of a boiler in connection with the chimney to which the boiler is attached. We have a small equipment in the laboratory which enables us to give the boiler the exact draft desired. Therefore, if the chimney is specified at 50 ft., the dimensions given as 16 × 20, the outside temperature given as zero, we calculate the draft, adjust the equipment to this draft, test the boiler under this draft and it must give rating. That is a way to overcome these difficulties.

The second question concerns the Kata thermometer. I know very well that a Kata thermometer cannot give more than the wet- and dry-bulb thermometer. But there are differences of opinion. We overcame the difficulties with the Kata thermometer by making the relative humidity in both rooms equal and by cutting down the air motion so far that practically no air motion existed.

The third question concerns pipe coils and testing radiators when partly shut off. I should like to make all these tests but you must remember that I cannot devote all my time to such very interesting questions. As far as I have time and I can help the Society in clearing up this matter, I would like to do it.

HEAT EMISSION, HEATING EFFECT AND HEATING EFFICIENCY OF DIRECT RADIATION

By Konrad Meier, Winterthur, Switzerland
MEMBER

THE heat emission of direct radiators is fairly well known. Such uncertainty as still exists, is due mainly to differences in the conditions of testing and discrepancies between the actual and catalog surfaces or, in other words, the prevailing irrational method of rating, which is deceptive to anyone not familiar with its origin. After all, square feet should be square feet and nothing else, although they may differ in heating value and cost. Hence, for the sake of clearness it would be desirable to have accurate figures in B.t.u. per square foot for the principal styles and patterns of radiators, worked out with standard equipment by some competent and disinterested party.

Such information could then be included by the manufacturer in his catalog data, perhaps in the manner of the tables published in The Guide of 1925–26. These are convenient and would meet the needs, if supplemented by outline drawings of the radiators tested. For those who are in the habit of calculating, in thermal units, the capacities are given in B.t.u. together with the surface. The latter retains the old way of rating to satisfy those who prefer it. As the tests are being continued, these figures for square feet might at the same time be checked and made to correspond with the actual surfaces, thus leading to the newer method and enabling the buyer to compare and readily judge the value received.

There seems no reason why the capacity of radiators could not be stated plainly in our trade literature just as we find it for blast heaters, blowers, pumps, etc., and data showing the capacity of boilers should be obtainable in a more definite and logical form. We ask for such information although we realize, that varying allowances must be made for certain factors bearing on the results. The situation is very similar in the case of direct heating. In working out his plans the engineer should consider such points as the heating effect of the radiator pattern he proposes to use and the heating efficiency attainable under the expected conditions. However, it will always be safer to do this individually on the basis of the facts involved in a given case, rather than by general assumption. For this purpose we still require some more specific and reliable information. Investigation along these lines would be distinctly serviceable in solving special problems, as well as for applying direct radiation to best advantage in general.

The *heat emission*, as found by condensation and expressed in B.t.u., represents the capacity of a radiator under stated working conditions. It is a quantity dependent on the shape, the arrangement and the proportions of the radiator surface as turned out by the manufacturer. The *heating effect*, on the other hand, is a quality more or less variable. Some kinds of radiator surface radiate relatively more heat in a horizontal direction, while others act essentially by convection or by warm air currents rising vertically. The air movement will depend, in a greater measure than the emission, on surroundings, or the currents created by the same. This is quite irrespective of any screening, which will change entirely the effect in

Note. Presented at Third Session of the Annual Meeting of the American Society of Heating and Ventilating Engineers, January 1926. Read by Prof. A. C. Willard in connection with the discussion of "Heating Effect of Radiators" and a "Proposed Code for Rating and Testing Radiators."

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so far as characteristic of design. The *heating efficiency* again, is a degree of utilization, which may be stated in percentages. As generally understood, it is the ratio between the heat actually utilized and that contained in the fuel. The losses incident to generating and transit have always received due attention, but there are further losses caused within the rooms, as in reality only part of the heat reaches the proper place and contributes to comfort at the right time. The ratio between this and the heat actually emitted by the direct radiator surface, is what may be termed the efficiency of radiation.

Too little attention has been paid to this point. In fact, the heat emitted and that utilized are often assumed to be identical. In practice we are often far from this ideal. For instance, an excess of heat delivered at the ceiling, where it is least needed, means increased heat transmission and leakage, which must be met before the occupied zone becomes comfortable. This adds to the tax on the boiler and in cold weather there will be undue forcing or failure to accomplish results. Many complaints are due to this cause: A great or small part of the heat goes astray without doing service.

An indication of the extent of these losses is contained in the two well known and widely accepted formulae for the periodical heating of halls.

$$W = F_k \frac{(t - t_o)}{2} + F_1 \left[23 + \frac{5(t - t_1)}{Z} \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$W = F_k \frac{(t - t_o)}{2} + F_1 \left[40 + \frac{10(t - t_1)}{Z} \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Formula 1 is applicable to systems with well distributed and correctly-placed radiators, while Formula 2 is intended for cases where the heating surfaces or warm air outlets cannot be located to best advantage. On the average, the latter calls for about 75 per cent additional capacity, the empirical constants being increased to cover the extra losses incident to poor distribution, because the lower strata of the hall cannot be warmed sufficiently without excessive heat overhead. The above factors of safety, therefore, assume a heating efficiency of only 57 per cent, with no consideration given to boiler and piping. If the latter, for example, give a utilization of 60 per cent, the efficiency of the apparatus as a whole will be only $60 \times 57 = 34$ per cent, which by no means represents the extreme occurring in practice. In a lesser degree, the allowances made for heating high rooms are merely a recognition of the increased difficulties in obtaining even temperatures.

The decided influence of proper distribution on heating efficiency is also shown by electric heating systems, particularly in small churches, where the heat is applied by tubing placed underneath the seats, supplemented sometimes by heaters below windows. Judging by numerous operating records, the consumption of current is smaller than that figured on the basis of Formula 1. Apparently, this would show more than 100 per cent efficiency. Actually, of course, the requirement is reduced below the calculated one owing to the local application of the heat, which gives higher temperatures in the occupied zones and accordingly keeps down transmission, absorption and indraught. Thus, by appropriate distribution it is possible to obtain comfort with less than one half of the heat output considered necessary in the older systems. And incidentally, the efficiency is further increased by shortening the time for reheating. The apparatus becomes more responsive and reliable, because it is dependent to a lesser degree on air currents for carrying the heat, showing that losses in the application of heat are by no means unavoidable.

While the efficiency of radiation is of prime importance in the design of apparatus for large rooms and unusual situations, in average practice it is perhaps a secondary consideration. However, there is sufficient evidence to prove that the losses due to faulty application of the heat are not a negligible quantity and should receive attention, if only on general principles.[1] Unfortunately or fortunately, it is difficult in occupied buildings to measure and to state them in percentages, but they can at least be detected by systematic temperature readings, giving the distribution of the heat within a room in horizontal as well as vertical planes. In fact, there ought to be a standard for heating, similar to the one which we now have for ventilation in the Synthetic Air Chart. The proper distribution, being a criterion of efficiency, together with sanitary quality, is essential for perfect heating and economy in the larger sense.

The question is now before us, how best to standardize and use tests for heat emission, investigate heating effects and get down to heating efficiency. Regarding the first point, we do not seem to be far from the goal. One of the problems still being discussed is the conditions of testing, which will have to be also considered in connection with heating effects and heating efficiency. On the two latter we have barely begun.

Some tests have been made to show the difference in the heat emission of one and the same radiator, when placed on an inside wall and underneath a window. The result was an appreciable increase of the condensation for the interior location; but it is still an open question, whether this holds true for all kinds of radiation. Moreover, the result throws no light on heating effect and is no proof whatever of greater heating efficiency. In so far as the increased heat emission is due to lower air temperature near the floor and rapid air circulation, it would, if anything, indicate the contrary. The heat from high radiators on inside walls will rise to the ceiling and there is consequently a counter current of cold air from the outside walls across the room, which is not conducive to comfort. The advantage of greater heat emission is, therefore, likely to be offset by increased losses overhead, and in order to arrive at some useful conclusion, we shall have to determine the amount of heat required to reach a carefully stipulated normal condition by the various methods of placing radiation. This result is not obtained by merely testing the heat emission and heating effect in combination, as has been proposed. This would tend to confuse the issue instead of clearing it, by separating the several points involved and getting the bearing of each on the results. This seems perfectly feasible, if special observations are made systematically and under like conditions.

To begin with, it will be necessary to agree on a standard for these, which need not be uniform for all kinds of direct surfaces. Very likely we shall get nearer to the desired facts, if each type is tested in the location for which it is intended, under windows or on the inside wall, not many patterns being suited or actually used for both. The aim should be to obtain figures representing usual working conditions and directly applicable to our work as far as possible. In that case there should be no need of a standard radiator for comparison. The recognized ways of measuring heat emission by the input will then be sufficiently accurate to obviate the need of checking them by the output, as suggested. It would be very difficult, in any event, to create a testing chamber that would also allow the measurement of the heat imparted to the air as a check on condensation under anything like working conditions, on the basis of which we must have the information. Nor will it be advisable to resort to a compromise as to location, such as the placing of

[1] See also "Economy in Heating," JOURNAL OF THE A.S.H.&V.E., 1918.

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the test radiator on a partition near the outside wall, which does not represent good practice, because it does not take care of down draught and infiltration, is not favorable for even temperature, takes up space, that is valuable for furniture or liable to be blocked by the same and too often merely represents the desire to compete with the cheapest form of radiation irrespective of suitability. This tendency ought to be discouraged and a standard selected which approaches an attainable ideal.

With identical conditions, we could then arrive at some comparative data on heating effect which might well be limited to the typical styles in different heights and depths. The percentages of heat emitted by radiation and convection will naturally bear on these results, but there seems no particular need of determining the exact ratio, since it would not give the temperatures obtained at stated distances in front of and above the radiator. What we desire is some positive data on the direction of the heat output, perhaps in the form of charts, to illustrate heating effect and responsiveness of different style radiators under known conditions.

Finally, we should have the truth about heating efficiency consistently built up on the same test conditions, but, preliminary to this, it will be necessary to agree on a standard of efficiency or of proper distribution of heat for perfect comfort, the usual thermometer at 5 ft. from the floor on a partition not being sufficiently reliable in this respect. It is well known that the temperature at knee height is a better indicator, but it seems desirable to go further and decide on a definite location, in reference to the windows, as representing the working zone. Observations to that end may prove to be of general interest and in addition show how far room temperatures could be lowered for equal comfort with even temperature throughout the room. The fact is, that between heating seasons, when such conditions generally prevail, most people are perfectly comfortable with the thermometer from 3 to 5 deg. fahr. lower than demanded in winter. Such differences are not fully explained by humidity, air movement or the thermal state of surroundings. It is probable that the distribution of the artificial heat is also a contributing factor.

On the basis of such a standard it will be possible to obtain comparative data on the amount of heat required for the desired result by different types of radiators, and with different locations or methods of placing, which may also show us impartially the merits of interior and exterior location. The inquiry should be extended to indirect and other systems and in particular to the various forms of concealed radiators, because this practice not only means a reduction in heat emission, always an uncertain factor owing to the vagaries of execution, but probably bears also on heating efficiency through the overheating of walls and the greater tendency of hot air to rise and escape. It might be shown for once, that screening is not only unsanitary and expensive, but wasteful in operation as well. It is certainly less efficient in point of service and, if we can show its fallacy from every point of view, it will help the movement for better and finer direct radiator surfaces.

Direct heating ought to be on the same plane with other building equipment in finish and general appearance. The aesthetic quality of the product would in due time remove the wish for all these makeshifts. Real progress in the arts will then have been aided by the tests on efficiency. Carried to their logical conclusion, these tests will surely develop new ideas in design, in which the desired function of a radiator will find expression, and suggest appropriate arrangement in place of shams. They could, furthermore, be made to show the advantages of a certain responsiveness of apparatus, and would back up the engineer in his efforts to secure the desired thermal qualities of the building, without which the best results are not attainable.

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No. 736

PROPOSED CODE FOR RATING AND TESTING RADIATORS

By R. V. Frost, Norristown, Pa.

MEMBER

EDITOR'S NOTE—The problem of rating and testing direct radiators is an important problem in the industry and is receiving very careful study through research. This presentation of a Proposed Code is for the sole purpose of starting a discussion on the subject and should not be interpreted as having the Society's endorsement, but should be considered as a preliminary step in developing a standard method of procedure for this work. Comment and constructive criticism are invited.

WHY does the heating industry retain the surface method of rating radiators? Why not adopt in place of it, the more convenient and reasonable method of rating by the heat emission in B.t.u.? These questions are becoming of utmost importance to the radiator industry, and circumstances are now developing that will shortly make the answering of them of great urgency.

The recent development of new radiator types has given these questions new force, for it is recognized that the new types are penalized by the present method of rating. Confronting the proposed plan is the psychological influence of an old established custom that does not readily give way to a recognized improvement. The surface method of rating originated with the first employment of steam and hot water methods of heating, and undoubtedly developed from the surface method of rating boiler capacity. It served its purpose well, but as in all industrial or scientific development, old methods must gradually give way to new, and here is the last stand of an old method.

As a unit of capacity, square feet of surface is found only in the catalogue ratings of boilers and radiators, and as a method for rating boilers, is even now fast breaking down. The B.t.u. is the only recognized unit used in the calculation of heat losses in buildings and in the capacity rating of all other classes of heating equipment. There is just as little reason for the continued use of the surface method in the rating of radiators as for its continued use in any of the other branches of the heating industry. In fact its continued use is a serious drawback to the highest development of this branch.

Paper presented at Annual Meeting of the American Society of Heating and Ventilating Engineers, Buffalo, N. Y., January, 1926.

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The B.t.u. heat emission method as now developed in the tables published in THE GUIDE 1925–26 is the most convenient, simple and reasonable, as well as the most accurate method with which engineers are at present acquainted. It is labor saving, for it permits direct reference from the heat loss calculations to the radiator capacity without intermediary computations. It is exact, for it permits the requisite balancing that is essential to the design of any high class heating installation.

A study of the heat emission values given in THE GUIDE tables shows that the rate, per square foot of surface, varies from 190 B.t.u. per hour to 310, a variation in excess of 60 per cent, or a variation from the normal 240 B.t.u., of nearly 30 per cent above or below.

HEAT EMITTED BY DIRECT RADIATION—TWO-COLUMN RADIATORS

Steam Temperature at 215 deg. fahr. *Room Temperature at 70 deg. fahr.*

LENGTH INCHES	No. OF SECTIONS	45 IN.		38 IN.		32 IN.		26 IN.		23 IN.		20 IN.	
		Rated Surface sq. ft.	Total B.t.u. per hr.	Rated Surface sq. ft.	Total B.t.u. per hr.	Rated Surface sq. ft.	Total B.t.u. per hr.	Rated Surface sq. ft.	Total B.t.u. per hr.	Rated Surface sq. ft.	Total B.t.u. per hr.	Rated Surface sq. ft.	Total B.t.u. per hr.
	1	5	1892	4	1586	3.33	1237	2.66	1100	2.33	967	2	823
5	2	10	2973	8	2475	6.66	2121	5.33	1736	4.66	1520	4	1313
	3	15	4039	12	3373	10.00	2903	8.00	2373	7.00	2093	6	1810
10	4	20	5142	16	4272	13.33	3675	10.66	3010	9.33	2666	8	2304
	5	25	6225	20	5172	16.66	4452	13.33	3652	11.66	3239	10	2798
15	6	30	7308	24	6072	20.00	5220	16.00	4289	14.00	3809	12	3292
	7	35	8390	28	6972	23.33	5992	18.66	4920	16.33	4376	14	3786
20	8	40	9476	32	7869	26.66	6768	21.33	5560	18.66	4943	16	4279
	9	45	10562	36	8766	30.00	7539	24.00	6197	21.00	5510	18	4772
25	10	50	11645	40	9668	33.33	8323	26.66	6832	23.33	6081	20	5264
	11	55	12727	44	10567	36.66	9112	29.33	7471	25.66	6648	22	5753
30	12	60	13810	48	11467	40.00	9888	32.00	8109	28.00	7213	24	6245
	13	65	14892	52	12367	43.33	10662	34.66	8746	30.33	7780	26	6738
35	14	70	15974	56	13266	46.66	11436	37.33	9383	32.66	8346	28	7232
	15	75	17058	60	14164	50.00	12210	40.00	10020	35.00	8897	30	7728
40	16	80	18143	64	15062	53.33	12987	42.66	10662	37.33	9464	32	8221
	17	85	19227	68	15960	56.66	13764	45.33	11299	39.66	10032	34	8714
45	18	90	20311	72	16859	60.00	14538	48.00	11933	42.00	10601	36	9209
	19	95	21394	76	17758	63.33	15310	50.66	12570	44.33	11167	38	9703
50	20	100	22478	80	18656	66.66	16080	53.33	13211	46.66	11736	40	10196
B.t.u. per Intermed. Section			1083	..	900	....	776	.....	638	.....	565	..	493
" " Sq. Ft. " "			217	..	225	.....	233	.....	240	.....	242	..	246
" " " End Surface			378		396	....	400	.....	413	.....	415	..	411

FIG. 1. TYPICAL EXAMPLE OF HEAT EMISSION TABLE

Then why do engineers endeavor to calculate the heat loss as accurately as they do, and in the end destroy that accuracy through the use of an antiquated method of radiator rating?

There are objections offered to the adoption of this proposed system. One of the strongest is that of manufacturers, who contend that as 60 per cent of the radiation sold is installed by men who pay no attention to the engineering phases of their work, and consequently would not look with favor on any other method of rating than the present surface method, the manufacturers cannot afford to make the change. If it is necessary to cater to this extent to the unprogressive element in the industry, it can easily be done by compiling the ratings in exactly the form given in the present tables in THE GUIDE (see Fig. 1) and this need not stand as the reason for the continued hampering of the great body of engineers upon whom the responsibility falls for the advancement of the great science of heating.

It is admitted that certain complications will develop as a result of this change, the most important of which will be in the price structure. Eventually the surface rating will be discontinued, to be superseded by weight per radiator section; and

the new price structure will be built upon the section as the unit, with the rate of emission as a supplementary factor. Then too, the efficiency of the radiator will become a basic factor, for if a new type radiator is developed that gives a greater heat emission per unit of weight, the manufacturer of that radiator is at once placed in an advantageous position. But these are situations that need not cause undue alarm; the important consideration at the present time is the adoption of a Code for the Rating and Testing of Radiators, which will embody the method of B.t.u. rating and will prescribe the method to be applied to determine the proper rating on the B.t.u. basis.

A proposed Code for this purpose is herewith submitted:

1. Every style and type of direct radiator manufactured shall be given a rating of capacity for heat emission in B.t.u., for each size from one section to 32 sections.

2. The heat emission in B.t.u. shall be determined by the heat output of the radiator instead of the heat input.

3. The term *heat output* is here used to indicate the heat imparted to the air and surrounding objects both by radiation and convection; and *heat input* as the heat transmitted by the steam condensed, or the hot water.

4. The radiator shall be tested for its capacity in a test chamber of standard size and construction.

5. The heat input shall be determined by weighing the condensation at the return end of the radiator in pounds of condensation per hour. The steam at inlet to the radiator shall be at least 98 per cent dry, measured by throttling calorimeter. The inlet and outlet connections between the radiator and the calorimeter and the radiator and drip point to receiver shall be insulated.

6. The heat output shall be determined by measuring the heat increase to the air from point of entrance to point of exit of the test chamber. The test chamber shall be air sealed and insulated so that leakage of heat through the walls of the test chamber shall not exceed one per cent of the heat input to the radiator. The volume of air passing through the test chamber shall be measured in cubic feet per hour by any device of sufficient precision to insure against errors greater than 2 per cent.

7. The temperature of the air shall be measured within 2 per cent of the total difference between the inlet and outlet temperatures. The temperature difference of inlet and outlet air shall not exceed 10 deg. fahr.

8. The air entering the test chamber shall not set up unusual air conditions about the radiator, and to check such contingency, recording thermometers shall be located at various points in the test chamber to determine the temperature of the air over the radiator, the temperature at the floor, knee height, breathing line and ceiling, at intervals of not to exceed five feet throughout the area of the chamber.

9. Light ribbon streamers, or air movement indicators shall be attached at each temperature measuring point to permit observation, through suitable apertures, of the amount of air movement in the chamber.

10. The air shall enter the chamber at usual room temperatures, or at the temperature at which the heat emission characteristics of the radiator are to be determined.

11. In the calculation of the heat output, correction shall be made for moisture content of the air and barometric pressure.

A careful study of this method of test will show that it permits the checking of the heat output against the heat input within a very small percentage of error, and that there is also great latitude in the range of capacities.

Moreover, practically every degree of air condition under which a radiator may be normally operated, can be duplicated and uniformly sustained for the period of test; and practically every contributing factor in the emission of heat can be isolated in such a way that its effect may be determined. Thus, this method not only permits exact determinations upon the heat emission of a radiator under usual operating conditions, but makes possible a more comprehensive research into the fundamental problems of heat emission than could heretofore be attained.

There are many who will not attach great importance to this method of test, who will hold that the present condensation methods are fully adequate; but there has been sufficient investigation, carried on by independent observers to demonstrate conclusively that there are untold latent possibilities in the development of new radiator designs, that can only be opened up by research such as this method of test makes possible.

DISCUSSION

R. V. FROST (WRITTEN): Before entering upon the discussion of this most valuable contribution to the technical literature of our industry, I would first express to Dr. Brabbée my appreciation for the tribute paid to my work of last year on the problem of heating effect, and the effect of enclosures upon radiators.

In his paper, Dr. Brabbée has brought out several important points, to which I would like to give special emphasis.

The statement quoted below, found at the bottom of p. 504, after the description of the three present day methods of testing radiators, is the keynote of the situation and cannot be too strongly emphasized.

> For such methods of tests the investigators assume as self-evident that each radiator is 100% useful in room heating. It is from this point that the new method must start. The assumed condition that a radiator is 100 per cent efficient in the above sense is not self-evident, on the contrary it is erroneous.

The importance of this point is very forcibly brought out by an illustration further on. In the results of the comparative tests on a 38 in. flue radiator with a 20 in. window radiator, Dr. Brabbée records that the window radiator showed 17 per cent greater heating effect with 11 per cent less condensation, or a total difference in efficiency of 30 per cent. I am able to give this point further support by quoting from my paper of last year on Enclosed Radiation, where I showed you that of two radiators of equal space dimensions but of different design, one with an enclosure and the other exposed direct, the enclosed radiator showed an increased efficiency of 22 per cent when the temperature was measured at the breathing line.

To further satisfy my own curiosity on this point, I have been carrying on some investigations in my own home since the heating season started. In the living room, a room 28 ft. long, I have at one end, a 2 column, 38 in. direct radiator of 60 sq. ft., and at the other end a 2 column 26 in. radiator of 36 sq. ft. set in an enclosure in the lower part of a built-in bookcase. The enclosure has a solid wood panel over the front of the radiator, with a grill at the bottom and at the top. The enclosure is insulated with asbestos air cell block, and the inside of the enclosure is lined with tin. In zero weather both radiators are required, but at 30 deg. and

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above, the enclosed radiator easily takes care of the heat requirements. To make my investigation, I have located in this room, nine thermometers, arranged in sets of three; one at the floor, one at breathing height and one at the ceiling in each set. None of the sets are closer than 12 ft. from a radiator. With only the enclosed radiator working, the three sets are fairly uniform, with about a two degree difference between the two ends of the room, and a difference of not to exceed 5 deg. between the floor and the ceiling, and not to exceed one degree between breathing line and ceiling. When the direct radiator is on together with the enclosed, there is no difference in temperature at breathing line, but on the set of thermometers nearest the direct, there is an immediate rise of the ceiling thermometer to such an extent that the difference ranged as high as 14 deg. between the floor and ceiling. Moreover, it is impossible to heat the entire room with the direct radiator alone, when the outside temperature is at 30 deg.

This demonstration is quite convincing to me that there is a great deal to be said in favor of the zone system of rating, advocated by Dr. Brabbée, and also that the greatest attention must be given to securing an even distribution of heat in working out the design of a radiator.

These demonstrations should be sufficient to clear away all doubt as to the question of relative values in radiator designs. If we are able to secure equal heating effect with a saving of from 20 to 30 per cent in fuel, the industry surely has an obligation to the public that must be met, and without delay.

Dr. Brabbée offers a suggestion in the following statement:

> One procedure would be for an independent laboratory under the direction of recognized authorities to test all radiators under standard conditions and in standard test rooms, in the manner which has just been outlined, and to publish the results in the form of tables.

Two statements in Dr. Brabbée's conclusion are significant and bear repeating for emphasis.

> (1) For the time being this method of determining the heating value of radiators is not only desirable but essential for correct design and judgment. We do not require a certain number of square feet of iron surface in our rooms, but a definite amount of heat properly distributed at knee height. Anyone familiar with standard radiator designs can easily construct a radiator with a large heating surface, but a comparatively small effective heat output at knee height.
>
> (2) When radiators are installed on the basis of their *Effective B.t.u.'s* as determined from this new method of test, their heating effect will be applied most economically for the engineer and most hygienically and to the greatest satisfaction of the occupant.

While Dr. Brabbée and myself have been working contemporaneously on the same problem, it has been without knowledge of one another's work, and it is quite natural that there should be some divergence of ideas.

My work on this one subject now covers a period of nearly twelve years and for something like ten years I have sought a method that would overcome faults that I felt were inherent in the comparative method. Therefore, while I recognize the value of the comparative method, I regard it merely as a stepping-stone to an ultimate method. In the discussion of this paper by Prof. Barker are several statements I will quote, which concretely express the situation in general.

> The comparative method is of course an empirical one. The progress of any science always results in replacing empirical methods by analytical ones. This method is, therefore, only a step, but a very useful one, towards the completion of the investigation.
>
> My viewpoint as to the future progress of the analytical investigation is as follows:

It appears self evident to me that if there are two radiators of which the total output is the same, and if that output is similarly subdivided in each case both as to amount and direction between convection and radiation, then the heating effect on any room whether measured by thermometer at knee height or in any other way, must be identical. In other words, the essential things which we require to know about the radiator itself, and apart from its effect on any particular room, are the amounts both of the convected and the radiated heat and the way in which these are distributed. The effect of any particular distribution on any particular room is a problem to itself, even more complex than the emission from a radiator.

I regard the room as producing negative emission which requires investigation on exactly the same principle as the positive emission from the radiator. The radiator is to be regarded as a positive emitter or negative absorber while the room is generally a negative emitter or positive absorber. The emission from the radiator and the absorption by the room are complementary phenomena. The effect on the room is the resultant of these two influences of which one is as important as the other. It would be a mistake, therefore, to regard individual experiments described in this paper solely as a test of the radiator. They are equally a test of the experimental room in which they are conducted. At this point I diverge from Dr. Brabbée's view on a matter of theory which does not affect my opinion of the experiments as a whole.

In proposing a Code for the Testing of Radiators it is this latter point that I had in mind and which may be summarized as follows:

Every contributing factor in the emission of heat must be isolated in such a way that its effect can be determined so that the fundamental problems of heat emission may be investigated.

The Code must, therefore, not be considered as contradictory to the comparative method but as embodying it, and as being analytical in method and calorimetric in principle.

In reference to the unit proposed by Dr. Brabbée for rating radiators, to which he has given the name *Standard Unit*, will not this plan prove more confusing than clarifying? It is in effect an attempt to retain the present surface unit and at the same time give it an exact B.t.u. value. It means an added step in the engineer's calculations, and will not satisfy the buyer who regards radiation as only so much iron.

Since we are now engaged in an endeavor to eliminate some of the rubbish that clutters up our calculations of heat transfer, let us cut it all away, drop that misnomer, square feet of surface, and take for our unit the one that Dr. Brabbée has shown so essential by constant use in his paper, that has been used in THE GUIDE for several years, and that is the general preference of engineers, namely, *B.t.u. per section*. Then if manufacturers will price their product upon the basis of weight per section, the industry will have taken a long step in that simplification in industry that is now so emphasized by Secretary Hoover of the Department of Commerce.

DR. C. W. BRABBÉE: I am very much pleased to learn that the fundamental idea presented in my paper is generally accepted. This means that we should study radiators not from their actual heating surface, not by weight, but by their output in different heights of the room. One objection made to this method by Mr. Frost was that the results obtained in our test rooms might not hold good generally because they are a function not only of the radiator but also of the test rooms themselves.

But it has already been stated in the paper:

The objection might be raised that relative values for radiators tested in these two rooms of equal heat loss would not hold good for other rooms. This might be true for exceptional cases, but for the great majority of practical installations the relative results obtained for a set of standard rooms can be taken as an excellent criterion for

classifying radiators within the limit of plus or minus two per cent of this method. I do not think this is an important disadvantage of this method, if normal rooms are used.

I further would like to remind you of the illustration cited in the paper that heaters tested relatively in two certain rooms and later tested in two entirely different rooms gave practically the same results.

Another objection raised to this method was that we could obtain relative results only. Let me illustrate this point. If I am going to buy some electric light bulbs, I may ask the dealer, "How powerful are these bulbs?" He will tell me, "Sixty candle power." What does that mean? Simply that this bulb gives out sixty times as much light as a standard international candle power. Before this international candle power was established, bulbs were classified by the wattage consumed, but it was soon found that some bulbs gave more light with less current. Therefore, this standard candle power helped to develop the light industry a great deal. I cannot see why this method of adopting a standard radiator will not help our heating industry in the same sense.

There is one point brought out in Mr. Frost's paper to which I would like to refer: "The heat output shall be determined by measuring the heat increase of the air from point of entrance to point of exit of the test chamber." Let us suppose we are going to test the sun's heat output. The sun primarily does not heat the air. But you know that if you are out in the open on a high mountain you are —even on a very cold winter day—warmed comfortably only by the radiation from the sun, if no wind is present. The sun tested in the proposed test chamber would show up as a rather poor heater. Therefore, I think this point should be studied very carefully.

Why are we looking for another test method for which we should have to spend a lot of money and a great deal of time, not knowing whether it would turn out to be of value or not, if we already have such a method, giving results that are in accord with our practical observations, where we have nothing to try and nothing to study, only to apply our knowledge.

W. H. CARRIER: I don't claim any particular knowledge as to the effect of radiation but I have had quite a little experience in testing and I want to say that I don't altogether agree with Mr. Frost. From the standpoint of an air engineer, I agree somewhat with what Dr. Brabbée has just said. I want to say first that I think this ought to be discussed, because here is a proposal for methods that are going to be carried out in our laboratory and if there are any ideas that other members have we ought to have their reactions. It is an important thing to have the tests conducted in such a way that they will give us real results and not start out with assumption which may after we get through be found to be faulty. I think one of the biggest mistakes made in any testing work is that the investigator often starts out with a certain preconceived idea and certain assumptions which are found not to be warranted. He obtains his results without taking these things into consideration.

I want to call your attention to this proposed introduction of air into the room. I want to ask Mr. Frost how he is going to introduce that air. I don't know how it can be introduced and have it represent normal conditions. If you introduce it from the floor, it is obviously wrong. Right away you get a stratification and an unnatural condition and the distribution will be unfavorable to the radiator efficiency. Shall you introduce it at the ceiling? Then you are introducing a condition even more unnatural, because then you are getting in some cases a very

much better uniformity of temperature than you possibly could get under natural conditions of convection. There again you are wrong. Where are you going to introduce it, at some intermediate point, or distribute it? It is a very difficult thing. It is quite true that a good deal of our heating is to take care of infiltration. What part we do not know definitely, but we may estimate it in certain special cases. We will say normally from one-third to one-half has to be taken care of and this is not distributed at any one point either on the floor or ceiling but occurs in leakage around windows and in some cases through the walls. Convection occurs on one, two or three exposed walls somewhat uniformly except in the case of windows. Mr. Frost has pointed out very well, that the problem is not one alone of emission of heat but negative emission of buildings. Unless we can adopt a standard room in which we can reproduce average standard conditions both of radiation and infiltration, we are going to make an assumption that when we get all our work entirely finished we will find our results are worthless.

I think this preliminary work needs to be given a great deal of thought, and after you have given it thought, prove that your assumptions are right by actual comparative tests. I would like to get the reaction of the members on that because this is an important thing if we are going to adopt the code for comparative tests.

R. V. FROST: Answering Mr. Carrier's question, which will also answer Dr. Brabbée's criticism. I did not touch upon the point in question in the paper, for the reason that it is a matter for research, but since the question has been brought out, I will offer this explanation:

Consider, first, a perfectly insulated room, having an air inlet and an air outlet; the exact locations of the openings being immaterial other than that they are in one wall. Next, consider that the radiator for test is placed along the opposite wall of this room and that separating the radiator from the air openings is a partition of one character or another, perhaps with a window, similar to the outside wall of a building. Now, suppose that air is passed through the outer chamber and that the heat increase to the air is measured. There would be no other loss from the radiator except the loss through the partition, which would be taken up by the air. This method, which is one of many that could be used, would obviate the difficulty that Mr. Carrier suggests.

J. A. GORTON (WRITTEN): The proper rating of radiators is a subject that is of great interest, not only to the heating industry, but to owners as well for they really are the ones most vitally interested.

Just what is to constitute a basis for rating a radiator is the question for discussion and one that must be considered from all angles before any definite recommendation can be made.

Based on my experience with the Plumber-Steamfitter who does practically all of the steam heating outside of large installations. I would suggest that the rating be given in "square feet" as it is now.

The B.t.u. rating can also be given in the same or a separate table for *engineering data*, but it should state what method of venting the radiator was used in making the test, which should be made under as near the average working conditions as possible.

The venting of a radiator is a very important factor to be considered for unless the radiator is properly vented it is absolutely impossible to get any where near full efficiency from it.

E. C. REED (WRITTEN): Relative to the rating of radiators, we do not at this time recognize the importance of such a move.

Granting that there is a variation in the heating efficiency per square foot of various types and sizes of radiators and that the B.t.u. value is theoretically more correct, there are many obstacles in our mind and quite a few objections. This first one is the real importance of the matter. The radiator, of course, consumes nothing—it simply transmits heat from one medium to another. Therefore, the only loss on a less efficient radiator is the first cost of the radiator and is not a continued penalty. Radiators are chosen largely for appearance or space condition rather than first cost.

It is also assumed that the conditions under which a test is made are the actual working conditions, while this is not in any way the fact. It might be extremely possible that one radiator might exceed another under the conditions of test and not equal it under certain working conditions. It, therefore, means in any event a margin of safety has to be provided as the conditions under which a radiator was installed might more than offset the theoretical difference in the radiator.

Most important of all is the basis of sale; radiators cannot be sold on weight as the article suggests, as certain radiators cost more to manufacture than others and are now being sold as closely as can be estimated on a cost basis. Added to which the article assumes that all manufacturers would subscribe to having their radiators tested by one agency, which will be considered authority. There is nothing to prevent different manufacturers entering into competition as to the value of their radiators from a B.t.u. standpoint the same as is claimed on boilers. Their competitors or some neutral agency might challenge their statements, but they can continue to sell on the basis of their own conclusion.

Boiled down, while it is admitted there are certain differences of efficiency, we now have a fairly accurate method of measurement of the radiators on which to base the sale. Any information you could get would be supplementary to this and could be obtained and used by any steamfitter who thought it was a step to progress regardless of the method of sale of the radiation.

If anybody can develop a radiator that will cost less and be of more efficiency that will be a real step to progress, but the testing of literally thousands of radiators of all the different manufacturers we do not feel is going to have a great deal of weight.

H. C. STRONG (WRITTEN): A few practical questions occur to us:

(1) Scientific determination that proposed method accurately determines efficiency.

(2) Who is to do that and who is to bear the expense of it?

(3) The merchandising problem of a price unit other than feet of radiating surface according to catalog ratings, bearing in mind the practical necessity of a price unit easily understood.

We are interested in and desirous of cooperating in any movement that has for its object the general improvement of the industry of which we are a part.

F. D. MENSING: I would like to make a motion. I know everybody is as much interested as I am and it has been the habit in the past to publish these discussions in the abstract. Interesting us all as they do I make the motion that: The discussions we have heard today be published in the next issue of THE JOURNAL in full in order that we may have time to digest them later.

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H. M. HART: I would like to present a motion. I move that the entire question of the Code for Rating and Testing Radiators be referred to the Technical Advisory Committee on Radiation, with power to the Committee to undertake such research as may be required in formulating the Code and to report its recommendations at the next meeting of the Society.

No. 737

FORCED HOT WATER SYSTEM HEATS FORD'S TWIN CITIES PLANT

By E. H. WHITTEMORE, BOSTON, MASS.

MEMBER

COVERING a tract of about 160 acres and partly situated on a high bluff 100 ft. above the Mississippi River at St. Paul, Minn., the Twin Cities plant of the Ford Motor Co. attests to the tremendous development of the automotive industry in that section of the country. The plant consists of a manufacturing and assembly building, oil house, steam power plant, hydroelectric plant, and considerable trackage area for transportation facilities. While built for that extreme efficiency of service that characterizes the owners, the architectural design of the several buildings has been given careful thought particularly on account of the unusual location resulting in a beautiful group of buildings harmonizing in a pleasing manner with the surroundings.

Millions of Cubic Feet to Heat

It is more particularly to the manufacturing and assembly building that this paper alludes, presenting as it does, on account of its unusual size, several interesting features in connection with the heating system. The building is 1400 ft. long, and 600 ft. wide with a combination saw-tooth and monitor roof. The bottom chord of the roof trusses is 16 ft. above the floor which is built directly on earth and the highest points of roof construction are approximately 40 ft. above the floor. Except for a relatively small section of the building in the northwest corner and an electrical substation near the center of the building, the entire structure is one large room. The computed interior cubical contents of the entire building is 31,704,300 cu. ft., and there are 327,740 sq. ft. of side wall and roof, glass and doors. The walls are brick and concrete varying from 13 in. to 44 in. thick with a net total of 70,170 sq. ft. The roof, of which there is 775,000 sq. ft., is partly wood plank with patented roofing and partly cement tile. A small portion of the outside edge of roof area is covered with Spanish tile for architectural appearance.

Forced Hot Water System Selected

The entire building is warmed by a forced hot water heating system using both

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cast-iron radiation and pipe coils, with one room in the office section using unit heaters.

Heat Losses Large

The total heat loss from the building computed at a temperature range of from —20 to +60 deg. fahr. in the manufacturing and assembly section and from —20 to +70 deg. fahr. in the office section is 123,338,000 B.t.u. per hour. In this figure due account has been taken of the high wind pressures to be encountered along the entire north and west sides, partially due to the extreme exposure presented by the high location on the edge of the river bluff. To compensate this loss approximately 480,000 sq. ft. of direct radiation has been installed of which 440,000 sq. ft. is in $1^1/_2$ in. pipe coils and 40,000 sq. ft. in cast-iron radiation of both column and wall type. The two unit heaters previously mentioned are used to heat the show room located at the extreme northwest corner where, on account of the large

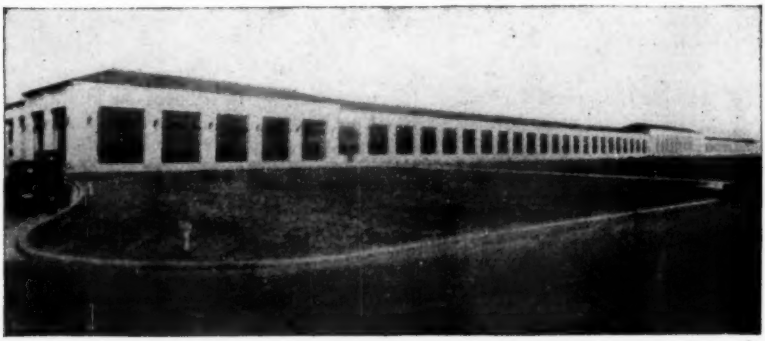

FIG. 1. THE TWIN CITIES' PLANT OF FORD MOTOR CO.

amount of window area, there was insufficient wall space available for the proper amount of direct radiation.

On account of large losses through roof and overhead sash areas and also in order to eliminate interference with the installation of machinery a large part of the heating surface is placed overhead in the roof trusses. This presented somewhat of a problem on account of the necessity of locating the coils so as not to interfere with the natural light. Cast-iron wall radiators are placed below the windows on the exterior walls, while radiation of the column type is used in general throughout the offices.

The portion of the roof along the entire north, west, and south edges of the roof and a short portion of each end of the east side is covered with Mission tile and is provided with a concealed gutter for drainage. In order to facilitate the melting of snow and ice in this gutter steam lines were carried in a concealed pocket or cavity directly behind this gutter and connections made at frequent points with control valves so that different sections could be turned on whenever necessary.

Power Plant Equipment

Heat is supplied from the steam power plant located at the river bank and about

300 ft. away from the westerly side of the building. This plant is equipped at present with two 1361 h.p. water-tube boilers using pulverized coal for fuel and generating steam at 275 lb. pressure. The generating equipment in the station consists of two 5000 kw. specially designed turbine driven units built by the Ford Motor Company and similar to a type used throughout many of their other plants. From the present turbine steam is bled at the 10-lb. stage to supply heating steam for the manufacturing building. This heating line is also cross-connected with the exhaust from auxiliaries and with the feed water deaerator. From the top of the steam station the piping is carried across a covered bridge and through a concrete tunnel running under the entire width of the building. This tunnel also houses

FIG. 2. VIEW SHOWING PIPE COIL ARRANGEMENT AND CONNECTIONS—NOTE RADIATORS ALONG SIDE WALLS

the coal handling conveyor and other pipe lines. Opening directly off this tunnel and in the approximate center of the building is a pump and heater room which accommodates the entire equipment necessary for heating the water used to warm the building.

In addition to the 24-in. 10-lb. steam heating main a 12-in. line is brought from the tunnel to the pump room carrying 125 lb. pressure. This is used to supply steam for manufacturing purposes as well as to drive the turbine driven circulating water pumps and supply make-up steam for water heating should the occasion require.

Water Heating Equipment

The pump room equipment consists of:

Two low-pressure closed heaters

Two high-pressure closed heaters
Two turbine and one motor driven centrifugal circulating pumps
One turbine and one motor driven condensate pump
Expansion tank
Air compressor

The water heating equipment and piping system is so arranged that the office section of the building may be operated separately from the rest of the building, having its own independent heater and circulating pumps. This section is also cross-connected with the regular heating equipment and may be used in conjunction with the rest of the system. The heaters used for warming the water for the heating system are two 5000 gal. per min. low-pressure heaters, ordinarily used to heat the water for the entire system, and one 5000 gal. per min. high-pressure heater to be used as a spare for the low-pressure heaters or as a booster for increasing the temperature of the water in weather of extremely low temperature, or to heat the building more quickly than would be usually required. A 250 gal. per min. heater has been installed for heating the water required for the heating system in the office section of the building when operated independently. The ratings of the above heaters are based on raising the temperature of the water from 170 to 200 deg. fahr. when supplied with saturated steam at 5-lb. gage pressure. The so-called high-pressure heater, however has been designed to heat 5000 gal. per min. from 200 to 230 deg. fahr. when used with steam at 15-lb. pressure. The low-pressure heaters have cast-iron shells while the high-pressure heater is steel. All are of the horizontal type with tubes of seamless drawn copper.

Pumps

Two turbine driven and one motor driven circulating pumps of 5000 gal. per min. each have been installed to handle the main heating system. For the office section heating system one turbine driven and one motor driven 250 gal. per min. pumps have been used. All pumps are of the horizontal double suction, single stage centrifugal type. Horizontal noncondensing single stage turbines designed to operate at 125 lb. per sq. in. gage with 25-lb. back pressure have been used. Motors are of the constant speed type operating at 440 volts, three phase, 60 cycle a.c.

Condensate from the heaters is handled through a receiving tank having installed in connection with it, one motor driven and one turbine driven condensate pump, and these are of similar type to the main circulating pumps, having a capacity of 300 gal. per min. against a discharge head of 28 ft. From this point the condensation from the water heaters is returned to a large surge tank in the Steam Station which also acts as a storage reservoir for condensate throughout the entire station from which point it is fed direct to the feed water heater by gravity.

The main expansion tank is located below the manufacturing building floor, and with the exception of one head and a short length of the shell which projects into the pump room it is entirely buried underground. This tank is 10 ft. in diameter and 15 ft. long of approximately 9000 gal. capacity, built of black steel plate with dished heads. In addition a similar tank 3 ft. 6 in. in diameter and 7 ft. 6 in. long of about 500 gal. capacity was installed for use with the office section system when running independently. A motor driven air compressor, having a capacity of 17 cu. ft. per min. at 100 lb. pressure, has been installed to maintain the necessary air pressure in this tank.

Details of Piping Design

Having determined the amount of radiation necessary to warm the building to the required temperatures, the next problem to be solved was that of designing a piping system which would distribute the hot water economically and efficiently. The design of any piping system for hot water heating while fundamentally a simple hydraulic problem, probably contains as many elements of uncertainty as any other particular problem in the field of heating engineering. This is due to the fact that but little data has been tabulated in a form to make it adaptable

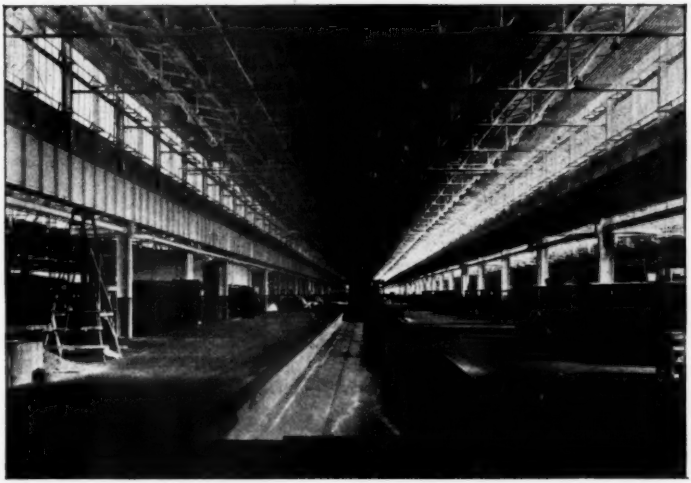

FIG. 3. SCENE IN SHIPPING BAY—CEILING COILS FURNISH HEAT

to all conditions. Many assumptions must be made and much practical data is entirely lacking. In addition there are several different methods of arriving at the desired result and on account of the different operations involved in each it is difficult to obtain a check on the whole problem until the final computations have been reached.

As applied to this particular layout the methods of solution followed in general the following outline:

The necessary flow in gallons per minute through various parts of the system was computed as follows on the basis of a 30 deg. temperature drop of the water:

Assuming a heat transfer factor of 2 B.t.u. per sq. ft. per hour per degree difference in temperature with water entering the coils at 200 deg. fahr. and leaving at 170 deg., or a mean water temperature of 185 deg. fahr., the total heat transmission through pipe coil surface would be 250 B.t.u. per sq. ft. per hour.

With a surrounding air temperature of 60 deg. fahr., it is found that 2×125 deg. $= 250$ B.t.u. per sq. ft. per hour.

For wall radiation a heat transfer factor of 1.9 B.t.u. per sq. ft. per hour per degree difference in temperature was used and for column radiation an average transmission factor of 1.75 B.t.u. per sq. ft. per hour per degree difference in temperature was used.

As the latter type of radiation was used in the office only where a room temperature of 70 deg. was maintained, the temperature difference of 115 deg. fahr. gives a heat transfer of 200 B.t.u. per sq. ft. per hour.

On the basis of a 30 deg. temperature drop through the piping system it is determined that 1 gal. of water per minute will deliver 15,000 B.t.u. per hour. Therefore, each gallon circulated per minute is sufficient to supply 60 sq. ft. of pipe coil radiation or 63 ft. of wall radiation, or 75 sq. ft. of column radiation, under the conditions in which the various types were used.

Commercial pipe sizes were selected on the basis of velocities of 5 to 8 ft. per

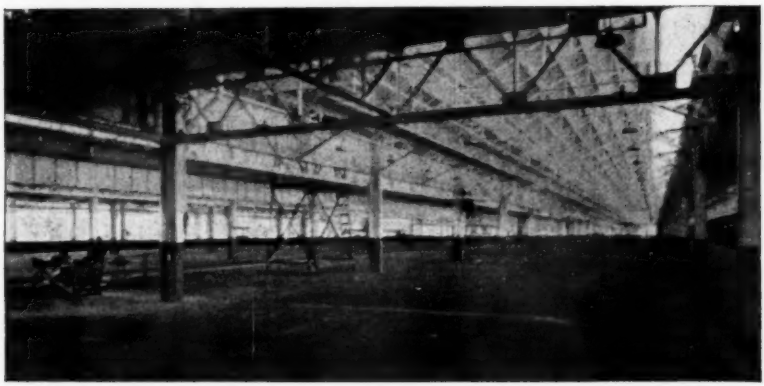

FIG. 4. GENERAL VIEW IN MANUFACTURING BUILDING

second and the resulting friction through the system was then computed. By the use of tables available for this purpose pipe sizes were then adjusted until the entire system was balanced as nearly as practicable.

The total friction head against which the pumps would operate was found to be approximately 100 ft. It is interesting to note that in checking this figure by two different methods, one of which took considerably longer time than a more simple system first used, produced a result which was within 4 per cent of the first computations, and required only one or two minor changes in the pipe sizes.

The piping system throughout the manufacturing building consists of what is commonly known as a reverse flow system with balanced mains. An attempt has been made to design the entire piping system to eliminate as far as possible the use of resistance control valves and from the result of preliminary tests it is believed that satisfactory results have been obtained. What would ordinarily be a difficult problem of distribution design has been made comparatively simple in this case on account of the symmetrical shape of the building and the almost equal division of the various sections. This fact, together with the extreme length of the building presents ample opportunity to divide the heating system into units of any desired size and has aided the solution of what ordinarily presents itself to the engineer

as a bothersome problem. From the pump room a distributing main 20 in. in size is carried through the pipe tunnel under the building and five points' connections are made to distributing mains which run practically an uniform distance through the building. Branches from these mains to groups of coils and radiators have been so proportioned as to compensate for friction losses and this has been made possible by selecting pipe sizes with a reasonable degree of accuracy and by varying the lengths of the pipe coils to provide a proper friction balance. Outlets have been provided at various points in the system for connecting test gages to determine the actual friction drop and it is hoped that future tests may provide interesting data to be checked against computations made in the course of the design of this system.

Special Equipment in Show Room

In one instance, as mentioned previously, a departure was made from the type of radiation generally used throughout the building on account of structural conditions. This occurs in the showroom which is located at the extreme northwest corner of the building. This room is used for the display of cars and has an extremely large amount of glass and exposed wall surface. This fact, together with the location of flood lighting fixtures, placed directly below the windows, made it difficult to locate sufficient direct radiation to properly warm this room. Unit heaters were therefore used and two of these were located in an adjacent room with circulation and supply openings extended through the intervening partition wall. These heaters utilize radiation of the copper tube type, and are of sufficient capacity to warm the entire room to 70 deg. fahr. at 20 deg. below zero. In order to compensate for unusual infiltration at this temperature or even lower, a small amount of direct radiation has been placed in convenient locations along the exterior walls between the windows. As exposed piping was objectionable in this room a pipe trench was run in the floor along the north and northwest walls directly below the radiators and piping connections brought to them through removable trench covers. Joints in this trench were entirely eliminated by the use of welded connections.

Upon completion of the system tests were made by taking temperature readings simultaneously at various points in the building and the outside temperature recorded at the same time. These readings covered a period of one week and while it was too late in the season to secure a severe test on the operation of the system the study of the results obtained indicates that a reasonably uniform temperature can be maintained throughout the building and that the radiation installed will maintain the desired temperature within the range upon which the design was based. Indicating and recording thermometers and gages have been installed in the pump room which will afford assistance to the operator in charge in maintaining the desired temperature throughout the daily weather fluctuations. It is believed that the maximum efficiency can be obtained in the operation of a system of this character in buildings of this type, particularly where the size of the system and the resulting character of the apparatus make it necessary and practical to have an experienced operator in charge of the system throughout the entire time.

In concluding it is hoped that this paper may have offered something of interest in connection with heating by means of forced hot water circulation. No claim is made for any ingenious or new method of designing a system of this type or for introducing any new features of design throughout the entire operation. An effort was made to keep the entire installation compact and simple, thus eliminating as far as possible interference with the installation of other equipment and also to provide a heating system that could be economically operated.

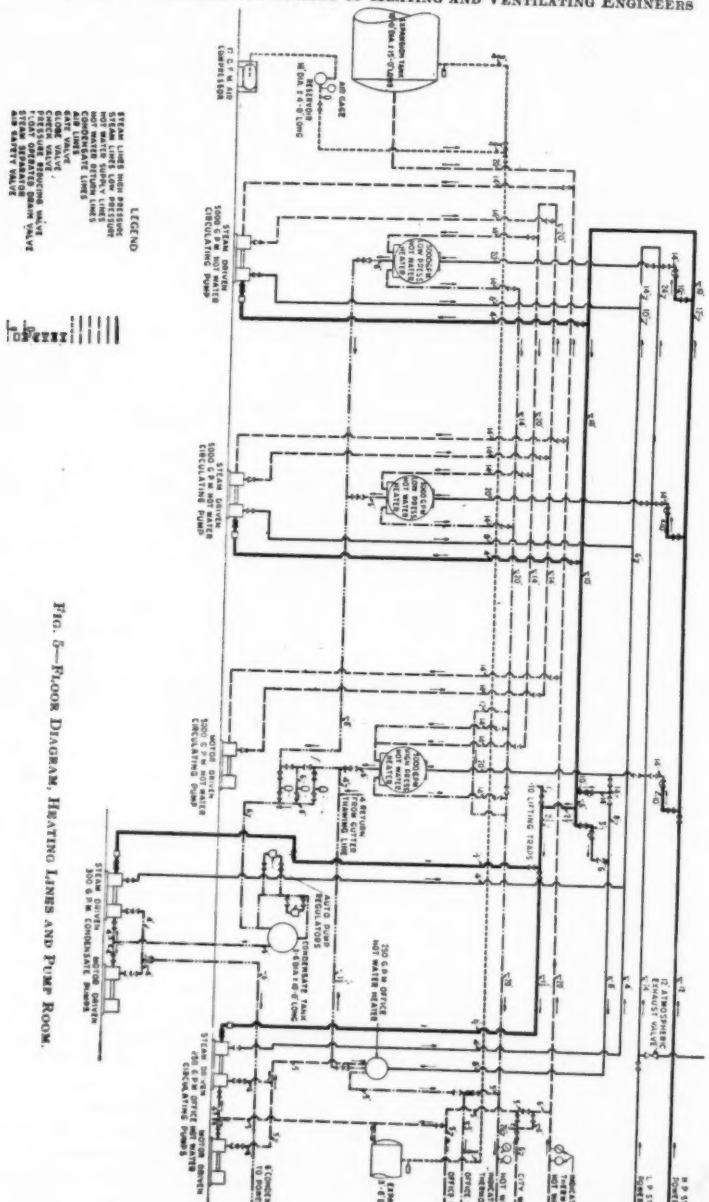

FIG. 5—FLOOR DIAGRAM, HEATING LINES AND PUMP ROOM.

DISCUSSION

PRESIDENT DRISCOLL: About a month ago I had occasion to drop into a prominent consulting engineer's office in one of the large cities of the country and I found three or four of his men around a table with our December JOURNAL before them studying this article word by word and figure by figure. They were very much interested in it. They had a problem of a similar nature to work on and this came in at a most opportune moment.

M. S. WUNDERLICH: I notice in this paper Mr. Whittemore gives the total heat loss of 123½ million B.t.u.'s. I would like to know how the heat loss was computed, whether the roof was taken separately and what was the assigned heat transmission factor. What was the total heat loss through the side walls and glass area, and what heat transmission constants were assumed? What was the assumed heat loss due to infiltration? It would be of great interest to me, as the building is in a rather exposed locality, where temperatures are low. I would like further to know what the final temperatures are, whether they were ever checked up under operation of −20 deg. outside with 60 deg. inside; the amount of water actually circulated and the temperature of that water supply and return.

E. H. WHITTEMORE: In regard to the computation of the heat losses I am not sure that I have the entire import of the gentlemen, because we used standard methods. In fact, I am inclined to believe at the time the computations were made on this particular project we were very much interested in the development of our new Code and we made an effort to carry out our computations in accordance with the general thought of the Code and see if they would check with our former methods. By taking each type of building construction separately and then both infiltration and air loss methods were computed and checked against each other.

As to the amount of water actually circulated and the information which is desired in connection with operating tests, I cannot give you very definite information at this time. The plant was only completed in the late winter of 1925 and it is hoped that through this winter we will have an opportunity to make those tests. If there is anything of interest in them I hope to have the opportunity to present them at some future time.

As to the check on the temperatures, we did take certain readings through the building during the coldest weather that we reached after the plant was completed last year. Those figures were in a very general way and as the temperature at that time did not get below 15 or 18 above zero they are hardly worth mentioning at this time. I would say, however, that they confirmed our general computation on the amount of heat required particularly with regard to the difference in temperature between the high strata and the low strata in that particular type of building.

G. B. NICHOLS (WRITTEN): The paper as presented by Mr. Whittemore represents a class of papers more of which should be presented to the Society as it describes in detail the essentials of a large installation giving basic figures which can be used on other work of a similar character. I have therefore made up a table giving the essential facts presented which should be printed in connection with the paper.
The following items I believe would add to the value of the paper:

Capacity of expansion tank and material of same.
Material of piping system.
Kind of joints used in pipe system.

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Method of taking care of expansion of pipes.
Were elbows or bends used in general piping system?
Cost of entire system.

SUMMARY OF HOT WATER SYSTEM FORD'S TWIN CITIES PLANT

Cubical contents of building	31,704,300 cu. ft.
Area glass in wall and roof	327,740 sq. ft.
Area of brick and concrete walls	70,170 sq. ft.
Area roof	775,000 sq. ft.
B.t.u. loss at −20° F.	123,338,000 B.t.u.
Total radiation	480,000
Radiation per cu. ft. contents	66
Temperature drop of water	30° F.
Temperature water entering coils	200° F.
Temperature water leaving coils	170° F.
Average temperature water in coils	185° F.
Heat transmission coils 250 B.t.u.	15,000 B.t.u.'s per hr. to system
1 gal. water circulated will deliver	60 sq. ft. of pipe coil
1 gal. water circulated per min. will supply	63 sq. ft. of wall radiation
1 gal. water circulated per min. will supply	75 sq. ft. of column radiation
Velocity water in mains	5–8 ft. per second
Friction head of pumps	100 ft.

MR. WHITTEMORE: The figures given by Mr. Nichols are substantially correct and are nearly all mentioned in the text of the paper. There are two expansion tanks, one for the entire system having a capacity of 9000 gal., and one for use when operating the office system independent of the rest of the building having a capacity of 525 gal. Both are constructed of black steel plate with riveted joints. The pipe used throughout the system is black steel, using screwed joints, all fittings 5 in. and over in size being flanged. Long radius fittings are used throughout and expansion of all lines is taken care of by means of double offset expansion U-bends, or 90 deg. bends where required, bends only being used for this purpose.

No. 738

THE NEUTRAL ZONE IN VENTILATION*

By J. E. Emswiler,[1] Ann Arbor, Mich.

MEMBER

THE term *neutral zone* has been used by Meier to designate the level, within a room, at which the pressure is just equal to that outside; but so far as the writer knows, it has never been extensively used in ventilation literature. It is the purpose of this paper to explain the relation between the position of the Neutral Zone and the motive heads arising from temperature differences available for causing flow, and to show in a general way how the idea of the Neutral Zone is helpful to a better understanding of several problems of ventilation, and more particularly how it may be applied advantageously in a consideration of the ventilation of large factory buildings by natural means.

In the attainment of this objective, it will be shown among other things:

1. That the head tending to cause flow at any opening, is proportional to the vertical distance of that opening from the Neutral Zone.

2. That the amount of air that may be passed by a given opening is proportional to the square root of the vertical distance of that opening from the Neutral Zone. Therefore, an opening located *at* the Neutral Zone is totally ineffective in passing air; and extreme openings near roof and floor of a building, are most effective.

3. That the position of the Neutral Zone, between roof and floor of a one-story building, is governed by the relative amount of opening provided at top and bottom, and by the difference of temperature between inside and outside air at different levels. With equal area and symmetrical arrangement of openings at top and bottom, and with uniform temperature difference throughout, the Neutral Zone will be at mid-height. If the area provided in upper sidewalls and roof is larger than that near the floor, the Neutral Zone will be displaced toward the roof; and similarly, if the lower area preponderates, the Neutral Zone will be displaced toward the floor. If the temperature difference between inside and outside air is less for the lower levels than for the higher, the Neutral Zone will be displaced toward the roof. In general, the Neutral Zone is displaced toward the group of openings of larger area, and toward the region of higher temperature difference.

The material herein presented has been developed in connection with an investigation of natural ventilation undertaken by the Engineering Research Department of the University of Michigan in cooperation with the Detroit Steel Products Co., Detroit, Mich., extending over a period of about three years.

When the air inside a structure, for example a single story factory building, is

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* Since the presentation of the paper the attention of the author has been directed to an article of similar title that had escaped his search of the literature, by L. Biro, a French engineer, translated and published in the Heating and Ventilating Magazine, June, 1912.

[1] Professor of Mechanical Engineering, University of Michigan.

Paper presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, Buffalo, N. Y., January, 1926.

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warmed to a temperature above that of the outside surrounding air, there results an immediate tendency for movement or flow to take place, cool air entering at lower openings, and warm air issuing from upper openings, if any are provided. The chimney and the warm air heating system are more familiar as examples to which the laws of flow have been applied, but the same fundamental theory, of course, applies in the consideration of any problem of flow resulting from a temperature difference. It is proposed to show how a better knowledge of the significance of the Neutral Zone in connection with the theory of flow is essential to the analysis of the less familiar problem of natural ventilation, and may be very

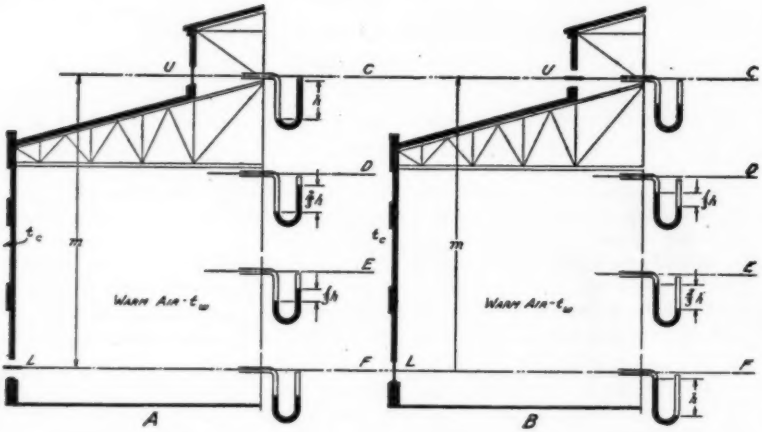

FIG. 1. WARM-AIR COLUMNS PLACED IN ATMOSPHERE OF COOL AIR; SHOWING DIFFERENCE IN PRESSURES WHEN A SINGLE OPENING AT TOP OR BOTTOM IS PROVIDED AS INDICATED BY LIQUID IN GAGES. NO FLOW OCCURRING

helpful in the better understanding of the more familiar examples of the chimney, the warm air furnace, and the gravity hot water heating system.

Pressure Zones Resulting from Temperature Difference

Fig. 1 represents a tall structure filled with warm air, placed in an atmosphere of cooler air. This structure is provided with ports or windows, *U* and *L*, located near the top and bottom respectively. It is also furnished with manometers or differential gages, which indicate the relation between inside and outside pressure at the four equi-spaced levels, *C*, *D*, *E* and *F*.

In Case *A* (Fig. 1), the upper window *U* is closed and the lower window *L*, opened. The pressures at the lower level, *F*, must be alike inside and outside, since there is direct communication through *L*, and no flow. The absolute pressure both inside and outside, will be less at the upper level *C* than at the lower level *F;* that inside will be less by the weight of the column of warm air; and that outside by the weight of the column of cool air of the same height. Hence, the pressure outside will decrease more rapidly upwardly from the bottom, than that inside. Warm air will be seeking to push its way out of the structure with an increasing intensity from the bottom, or place of equality, toward the top where the full head *h* (repre-

senting the difference between the weights of the columns of cool and warm air of height m) exists, and is manifested in the deflection of the liquid in the uppermost gage.

In Case B (Fig. 1), the upper window U is opened, and the lower one L closed. Again, no flow can take place. Equality of pressure is now established at the upper level C by direct communication between inside and outside through opening U. The absolute pressure, both inside and outside will be greater at the lower level F, by the weights of the respective columns. Since the cool air is heavier, it will be found that the outside pressure increases more rapidly, downwardly from C, than the inside pressure. The increasing excess of outside pressure at the level, C, D, E and F, is illustrated by the increasing deflection of the liquid in the four gages of Fig. 1—Case B, with the full head h now indicated by the lowermost gage. In other words, a vacuum of h inches exists within the building at level F.

In Fig. 2, the lower window L has been opened and in response to the difference of pressure that existed there in Fig. 1—Case B, air begins to flow in at the bottom. The inflow here will tend to raise the pressure all the way up, and cause an excess of pressure inside at the upper opening U, resulting in an outflow there. If the incoming cool air at the bottom be warmed by some heat source to maintain the temperature t_w of the warm column, a permanent condition of flow has been established.

Notwithstanding the fact that the warm air column is now in motion, the total head is no different than it was when the condition was static, as in Fig. 1, because the difference in weights of cool and warm columns is the same as before. With the air in motion, the total available head is used up in overcoming resistance to flow which is opposition to motion. In the case of Fig. 2, the total resistance may be considered as made up of three elements, *viz.*, the resistance at entrance at window L; the resistance of internal obstructions; and the resistance at exit at window U. Of these, the second may be reasonably omitted as a negligible factor in the case of most buildings. For the purposes of this paper, the total opposition to flow will be considered to consist of the inlet and outlet resistances.

If, in Fig. 2, the two openings U and L be of the same area and kind, it is clear that, neglecting change of volume of the air caused by heating, it will take half the total head to squeeze the air in through L, and the other half to squeeze it out through U. Hence the lower gage at F, will indicate a *vacuum* of $\frac{1}{2}\ h$, and the upper gage at C, a *pressure* of $\frac{1}{2}\ h$, existing within the building.

In Fig. 3—Case A, let the upper window U be partially closed, to such a degree that the resistance there is three times that at L. It will therefore require three-fourths of the available head to get the air out through U, and one-fourth to get it in through L. In Fig. 3—Case B, the lower window L is partially closed, to such a degree, that the resistance there is three times that at U. Here then three-fourths of the available head is required to get the air in at L, and one-fourth to get it out at U. The pressure distribution is illustrated by the levels in the gages in Fig. 3. In Fig. 3—Case A, the gage at level D will indicate rather strong pressure. There may be some doubt about the one at E, but it would in fact indicate a slight pressure, as shall be seen later.

The Neutral Zone

It is apparent from a consideration of Figs. 2 and 3, that there must be some point between U and L, at which, if there should happen to be a gage attached, the indication would be zero. This level is called the *neutral zone*. At all levels

below the Neutral Zone, there is a slight vacuum, increasing in magnitude in proportion to the distance from the Neutral Zone; and similarly, at all levels above the Neutral Zone, there is a slight excess of pressure inside over that outside at the same level, increasing with the distance from the Neutral Zone. If another opening should be made in the wall at any point below the Neutral Zone, inflow would occur there; and outflow would take place through any opening made above the Neutral Zone. An opening *at* the level of the Neutral Zone would be totally

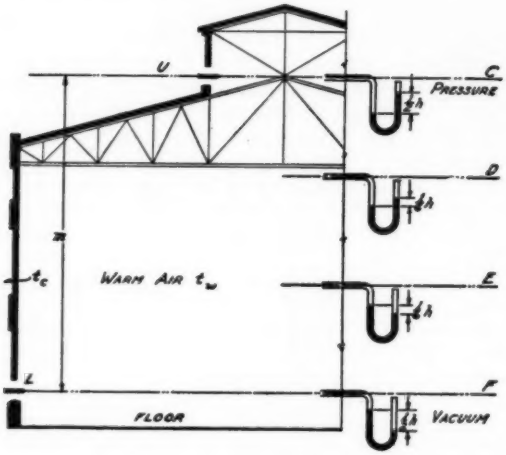

FIG. 2. ILLUSTRATING PRESSURE RELATIONS WHEN "U" AND "L" ARE OF EQUAL AREA, AND FLOW RESULTS FROM TEMPERATURE DIFFERENCE

ineffective; neither outflow nor inflow would take place because there is no pressure difference to cause motion.

Head Resulting from Temperature Difference

It has already been seen that the head or motive force that causes movement of air, in the foregoing illustrations, is measured by the difference in weights of two columns of air of different density. This difference of weight is determined by the temperatures and the height of the columns. Whether the columns are static or in motion makes no difference in the weights or difference of weights. The available head is independent of either the magnitude of the resistance or its distribution. In the case of Fig. 1, the resistance is infinite; in Figs. 2 and 3, it is differently distributed for each case. But in every instance, granting that the temperatures t_c and t_w are alike respectively, the head is the same. Hence the head available to overcome resistance and cause flow, may be computed in terms of temperatures and height of columns.

An expression for head can be derived from the fundamental laws of physics and mechanics, and may be found in various forms especially in literature relating to

the theory of chimneys. For the present purpose, where the application is to problems in ventilation, the writer has derived the expression:

$$h_a = \frac{mD}{T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where h_a = head in feet of air caused by difference in weight of the two columns.
D = difference in temperature ($t_w - t_e$, Figs. 1, 2, 3) deg. fahr.
T = average absolute temperature of the two columns $\left(\frac{t_w + t_e}{2} + 460\right)$

Heads are usually measured in inches of water. An inch of water corresponds

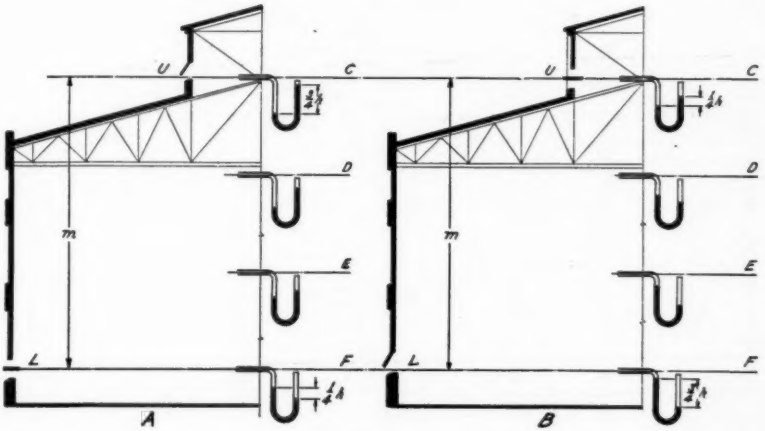

FIG. 3. PRESSURE RELATIONS WHEN OPENINGS "U" AND "L" ARE OF UNEQUAL AREAS

to about 75 ft. of air. That is, the weight of a column of air 75 ft. high, at ordinary barometric pressure and average ventilation temperatures, would balance one inch of water. Hence, the equation may be written:

$$h \text{ (inches of water)} = \frac{m\,D}{75T} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Thus, in Fig. 1, if $m = 50$, $t_w = 90$ and $t_e = 70$

$$h = \frac{50 \times 20}{75 \times (80 + 460)} = 0.0247 \text{ in. of water}$$

which would be the pressure indicated by the uppermost gage in Fig. 1—Case *A*, and the vacuum indicated by the lowermost gage in Fig. 1—Case *B*.

In Fig. 2, the gage attached at the bottom would indicate one-half of 0.0247 or 0.0123 in. of *vacuum;* and that attached at the top would show 0.0123 in. *pressure*. The total head available to produce flow is 0.0247, the same as in Fig. 1.

The Head at an Opening Is Proportional to Its Distance from the Neutral Zone

Referring again to Fig. 3—Case *B*, it is apparent by an inspection of the indication of the gages, that proceeding from the bottom upward, the state within the structure changes from vacuum to pressure at some level between *D* and *C*, which level is what may be defined as the Neutral Zone. Here an opening could be cut in the wall, and no inflow or outflow would take place, and the originally established flow through the structure would not be disturbed in the least. To go even further, cut the building in two on the Neutral Zone, separate the sections, and, provided the same temperature was maintained in the separate pieces as existed there when

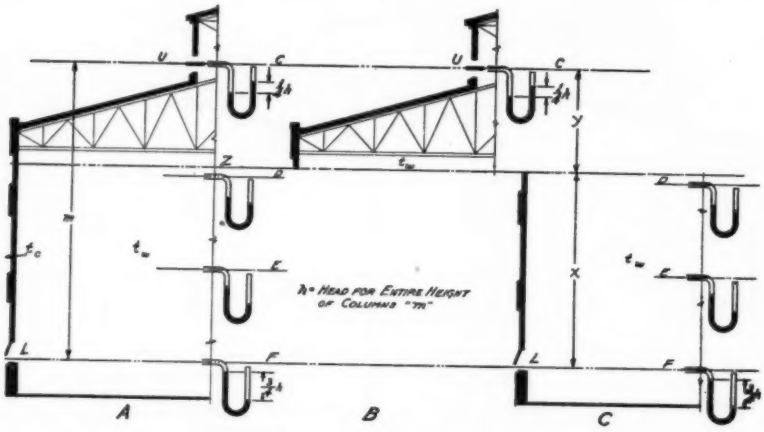

FIG. 4. SHOWING HOW THE TOTAL HEAD IS DISTRIBUTED TO UPPER AND LOWER OPENING IN PROPORTION TO THEIR DISTANCE FROM THE NEUTRAL ZONE

they were united, the flow *Q* through the two sections would be equal to the flow through the original solid structure; and all the gages would go on indicating the same deflections as they did before. Fig. 4 illustrates this idea, where *A* is the same as Fig. 3—Case *B;* while *B* and *C* show the full figure cut across with the sections displaced from each other.

The upper section may be thought of as a complete structure in itself, of height *y*, with an inlet opening so large as to offer practically no resistance to flow. The entire head is the result of the difference in weights of the columns *y* ft. high, or,

$$h_v = \frac{yD}{T} \qquad (3)$$

where h_v = head (in feet of air)
y = height of columns, feet
D = difference in temperature $(t_w - t_o)$
T = average of the two temperatures in deg. fahr. absolute.

This entire head, h_v, is available for overcoming the resistance of the upper opening *U*.

Similarly, for the lower section, Fig. 4—Case *C*, the head available for overcoming the resistance of the lower opening *L*, is h_L, where

$$h_L = \frac{xD}{T} \quad \ldots\ldots (4)$$

These statements are true, no matter whether the two sections of the structure are being considered, Fig. 4—Case *B* and 4—Case *C;* or the structure as a whole,

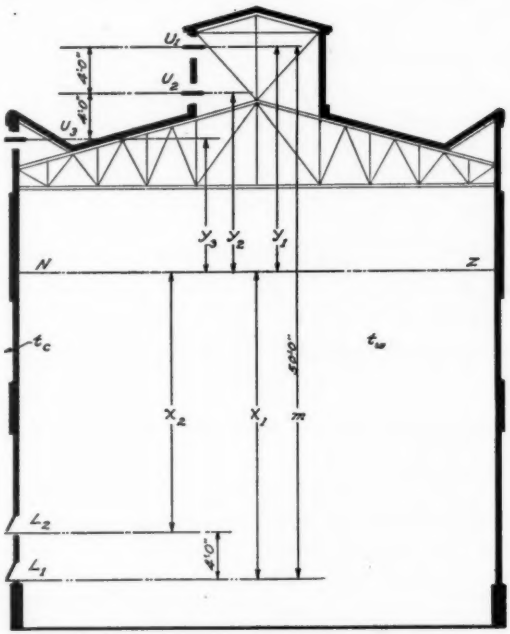

FIG. 5. ILLUSTRATING CASE OF SEVERAL OPENINGS AT VARIOUS LEVELS

Fig. 4—Case *A*. Thus there has been established the important principle that the head available at any opening is proportional to the distance of that opening from the Neutral Zone, which may be expressed by a general equation:

$$h_z = \frac{zD}{T} \quad \ldots\ldots (5)$$

where z is the distance of *any* opening from the Neutral Zone.

As a further illustration, take Fig. 5, which represents a more general case, wherein there are several openings near the top and near the bottom of the structure, at different levels, which is a common situation met with in large factory buildings.

In Fig. 5, inflow takes place through the two lower openings, L_1 and L_2; and outflow (presumably) through the three upper openings, U_1, U_2 and U_3. The resistance of L_1 and L_2 is much greater than that of U_1, U_2 and U_3. The air has a harder time, so to speak, getting through L_1 and L_2; or it requires a greater motive pressure at the lower openings than at the upper, to push the flowing air through. The Neutral Zone will automatically take such a position that the head at each opening will assume a value such that the total inflow will equal the total outflow, which, of course, is the necessary condition of equilibrium. The head available at any point, or level, is proportional to the distance of that level from the Neutral Zone.

Relation of Flow to Head and Resistance

The amount of air passing through any opening per unit of time is determined by the head or pressure difference on the two sides of the opening, and the resistance of the opening. The relation among these three quantities is similar to that which prevails in electrical circuits where

$$E = IR \quad \ldots\ldots (6)$$

wherein E = electromotive force, or electrical head available for pushing current through a conductor
I = current or electrical flow
and R = resistance, or opposition to flow

In the case of air flow, a similar equation applies:

$$H = Q^n R \quad \ldots\ldots (7)$$

wherein H = motive pressure or head available for pushing the air through an opening
Q = flow of air
and R = resistance of the opening.

In the use of the equation, the units must be properly chosen or related.

The head H must be expressed in *feet of air*—that is, it is the pressure or weight of a column of air H feet high. If any other substance were under consideration, such as water, then H would be expressed in feet of water.

The flow Q must be expressed in cubic feet per second.

R may be thought of as a characteristic of the opening or conductor through which flow takes place, and is numerically equal to the head in feet necessary to push 1 cu. ft. per sec. through.

The value of the exponent n may vary somewhat for different conditions, but experiments tend to confirm the choice of 2 as a satisfactory value for ventilation work.

The equation then takes the form

$$H = Q^2 R \quad \ldots\ldots (8)$$

The resistance of an opening is determined by its area and individual peculiarities. The latter factor is usually expressed by a coefficient C, in the equation

$$Q = AVC \quad \ldots\ldots (9)$$

where Q = volume of flow per sec.

V = velocity, ft. per sec.
and C = a coefficient, less than unity

The relation between resistance on the one hand, and area and coefficient on the other, is readily found to be:

$$R = \frac{1}{2gA^2C^2} \quad \ldots\ldots (10)$$

where R = resistance of a given opening
g = 32.2
A = clear area of opening in sq. ft.
and C = a coefficient expressing individual peculiarities of the opening. For ventilation work, experiments show that C has a value between 0.60 and 0.70.

Calculation of Flow

Armed with the working equations (5), (8) and (10) an attempt at the solution of a problem can be made.

Referring again to Fig. 5, suppose the following information is at hand:

Vertical distance between centers of extreme windows U and L = 50 ft. = m.
Vertical distance between L_1 and L_2, U_1 and U_2, and U_2 and U_3 = 4 ft.
Outside temperature, t_e = 40 deg. fahr.
Inside temperature, t_w = 60 deg. fahr. (assumed uniform)
Area of L_1 = area of L_2 = 50 sq. ft.
Area of U_1 = U_2 = U_3 = 100 sq. ft.

The problem is to determine the amount of air passing through the building per minute.

Applying equation (10)

$$R = \frac{1}{2gA^2C^2} \quad \ldots\ldots (11)$$

g = 32.2
A (for L_1 and L_2) = 50 sq. ft. A^2 = 2500
A (for U_1, U_2 and U_3) = 100 sq. ft. A^2 = 10,000
C may be taken as 0.65; C^2 = 0.42

Whence for each of the lower openings,

$$R = \frac{1}{64.4 \times 2500 \times 0.42} = 0.0000148 \quad \ldots\ldots (12)$$

and for each of the upper openings,

$$R = \frac{1}{64.4 \times 10{,}000 \times 0.42} = 0.0000037 \quad \ldots\ldots (13)$$

Combining equations (5) and (8)

$$\frac{zD}{T} = Q^2R$$

$$Q^2 = \frac{zD}{RT}$$

and

$$Q = \sqrt{\frac{zD}{RT}} \quad \ldots\ldots (14)$$

Substituting $D = 60\text{–}40 = 20$ and $T = \frac{60 + 40}{2} + 460 = 510$ in (14)

$$Q = \sqrt{\frac{z \times 20}{R \times 510}} = 0.198 \sqrt{\frac{z}{R}} \quad \ldots\ldots (15)$$

The Neutral Zone (Fig. 5.) must assume such a position that the total inflow will equal the total outflow. The simplest and easiest solution to determine this position will be found in the assumption of a number of different positions for the Neutral Zone, calculating, for each position, the flow through each of the five openings, by means of equation (15) inserting the value of z appropriate to the assumed location of the Neutral Zone. The correct assumption will be indicated when the total inflow is equal to the total outflow.

The various assumptions made together with the results of the calculations for each, are presented in Table 1. To show how the calculations are made, consider the first assumption. It is certain from an inspection of the problem as illustrated in Fig. 5, that the Neutral Zone will be nearer the extreme upper opening U_1 than to the extreme lower opening L_1. Assume that it is 30 ft. from L_1. This fixes the values of x_1, x_2, y_1, y_2 and y_3. The flow through the opening L_1 is given by equation (15) with value of $z = x_1 = 30$, and with $R = 0.0000148$, eq. (12)

$$Q \text{ for } L_1 = 0.098 \sqrt{\frac{30}{0.0000148}} = 282 \text{ cu. ft. per sec.}$$

Similarly, the flow for L_2 is computed, using $z = x_2 = 26$. The flow for the window U_1 is found by using $z = y_1 = 20$, and $R = 0.0000037$ (eq. 13)

$$Q \text{ for } U_1 = 0.098 \sqrt{\frac{20}{0.0000037}} = 461 \text{ cu. ft. per sec.}$$

and that for U_2 and U_3 are calculated in similar manner using $z = y_2 = 16$, and $z = y_3 = 12$ respectively.

For this first assumption, the total inflow amounts to 545 cu. ft. per sec. and the total outflow, 1229 cu. ft. per sec. This result shows that the Neutral Zone as assumed was too low, and acts as a guide in making the next assumption, represented by the second line of Table 1. The fourth assumption of the Neutral Zone position, 42 ft. above the lowest opening, is found to be too high. The next assumption of 41 ft. is found to give almost exactly equal inflow and outflow, and is therefore correct.

It will not usually happen that the correct position will be found so readily and exactly as in the fifth line of the Table 1. In case this last chosen value had not shown an almost exact equality between inflow and outflow, the correct position of the Neutral Zone could be found by plotting the inflow and outflow values against some distance representing the position of the Neutral Zone, as for example x_1, as is done in Fig. 6.

The solution shows how the excess of opening in the upper part of the building brings the Neutral Zone much nearer the roof. In fact it is seen that it lies only 1 ft. below the center of the window U_3, which makes this window rather ineffective in passing air. The conditions here would be found to be unstable. If there were no motive agency other than temperature differences, there would be inflow, at the lower part of the opening, and outflow at the upper. On the other hand, if there were present any other agency, such as the wind, it would probably be found that there would sometimes be outflow and sometimes inflow. The heads, in the vicinity of the Neutral Zone, are so minute that they may be overcome by the slightest disturbance. A window located near the Neutral Zone contributes but little useful effect.

Several other points of interest and significance may be noted in the solution of the problem. (See last line of Table 1, and Fig. 5.) Although window L_1 is

TABLE 1. SOLUTION OF PROBLEM—SEE FIG. 5

Position of Neutral Zone to Give Following Values of "Z" (Eq. 15)					"Q" For Each Window by Equation 15 $Q=1.36V\sqrt{h}$ "Q" is in Cu Ft Per Sec.					Total Inflow C.F.S.	Total Outflow C.F.S.
X_1	X_2	y_1	y_2	y_3	L_1	L_2	U_1	U_2	U_3		
30	26	20	16	12	282	263	461	412	357	545	1229
35	31	15	11	7	304	286	399	342	272	590	1013
40	36	10	6	2	325	309	325	252	146	634	723
42	38	8	4	0	334	317	291	206	0	651	497
41	37	9	5	1	330	313	309	230	103	643	642

opened to but one-half the effective area of U_1, the flow through L_1 is 330 cu. ft. per sec. as compared to 309 cu. ft. per sec. for U_1, or the ratio is 1.07 to 1.00. The velocity through L_1 is 6.6 ft. per sec., while that through U_1 is 3.1 ft. per sec. The disparity between areas of inlet and outlet openings requires that the activity of the former shall be much greater than the latter, which in turn necessitates the displacement of the Neutral Zone far toward the top, in order to realize the necessary distance to give the required head.

If a draft gage were connected at the level of L_1, its indication could be predicted by equation (2)

$$h = \frac{mD}{75T}$$

wherein m is to be replaced by $x_1 = 41$, the distance from L_1 to the Neutral Zone. Then

$$h = \frac{41 \times 20}{75 \times 510} = 0.0214 \text{ in. of water.}$$

The indications of draft gages if attached on a level with the centers of each of the openings have been computed in similar manner. and are shown in Table 2.

The thing that compels interest about these values of pressure or heads is the minuteness of their magnitude. Yet the aggregate flow maintained by these minute pressures, as worked out in Table 1, is 642 cu. ft. per sec., which is over 38,000

cu. ft. per min. Very small forces, if distributed over large areas, may be productive of enormous flows.

TABLE 2. PRESSURES THAT WOULD BE SHOWN BY DRAFT GAGES AT CENTERS OF OPENINGS. FIG. 5

Opening	Indication of Gage Inches Water	Pressure or Suction
L_1	0.0214	Suction
L_2	0.0193	Suction
U_1	0.0047	Pressure
U_2	0.0026	Pressure
U_3	0.0005	Pressure

Effectiveness of Area of Openings

In terms of quantity of air passing through it, the effectiveness of an opening is proportional to the square root of its distance from the Neutral Zone. Thus if one opening is 9 ft. from the Neutral Zone, and another opening is 36 ft. from the Neutral Zone, all other factors being equal, the second will deliver twice the volume of the first one.

In the example the total flow of 642 cu. ft. per sec., was participated in by all five openings, aggregating 400 sq. ft. in area. This would amount to 3.21 cu. ft. per sec. per sq. ft., as the average activity of the openings. Referring again to Fig. 5, let it now be assumed that the two windows L_1 and L_2 be opened to their full capacity, *viz.*, 100 sq. ft. each, thus giving an aggregate area of 500 sq. ft. instead of 400, as before. Assuming the same temperatures to prevail as in the original problem, *viz.*, 40 and 60 deg. and solving the new situation in the same manner as heretofore described, it is found that the resulting flow will be 1135 cu. ft. per sec. and the Neutral Zone will establish itself at a height of 32 ft. 4 in. from L_1. Thus an increase of area of 100 sq. ft. has increased the flow from 642 to 1135 cu. ft. per sec. resulting in an average activity 4.54 cu. ft. per sec. per sq. ft. of area. The Neutral Zone has been brought down from 41 ft. to 32 ft. 4 in.

As another supposition, let the opening U_3 (Fig. 5.) be closed, leaving L_1, L_2, U_1 and U_2 each equal to 100 sq. ft. The Neutral Zone will now lie at the level of mid-height, and the flow is easily computed and found to be 987 cu. ft. per sec. With an aggregate of 400 sq. ft. of area, this flow represents an average activity of 4.98 cu. ft. per sec. per sq. ft. of area.

Finally, if the two windows L_2 and U_2 be closed, leaving only the extreme openings effective, the flow will be 515 cu. ft. per sec. which represents an activity of 5.15 cu. ft. per sec. per sq. ft.

The example and its variations show that the effectiveness of openings as represented by the average flow per square foot of opening, is a maximum when the distribution of area above and below is symmetrical, resulting in the location of the Neutral Zone at the mid-point between; and that the extreme uppermost and lowermost openings are the most effective in flow, as would, of course, be expected. In other words, for maximum flow or ventilation, the areas of inflow and outflow openings should be equal, and should be located as near the bottom and top of a building as possible.

Case of Non-Uniform Temperatures at Different Levels

In the example discussed above, it was assumed that the temperatures both inside and outside the building were uniform throughout the height. While the

outside temperature, in actual practice, is likely to conform to this assumption, it is possible that the inside temperature may vary. If data are available giving the temperatures at various heights the problem is still easily capable of solution, but requires a little more labor in the calculations. The procedure is exactly like that which resulted in the figures presented in Table 1, except that for each assumption made for the position of the Neutral Zone, the average difference of temperature for the section of the building between the Neutral Zone, and the opening for which flow is to be computed, must be used, resulting in a different value of D and T (of equation 5) for each different opening. Non-uniformity of temperature will result in a displacement of the Neutral Zone from midposition even when the area of openings is symmetrically disposed in the upper and lower

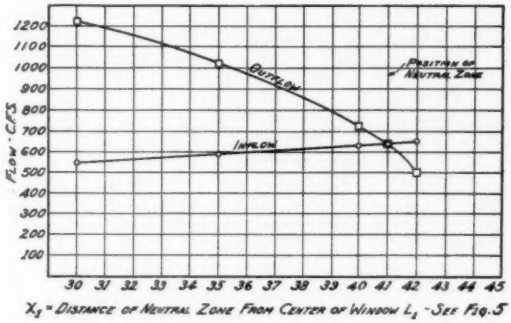

FIG. 6. PLOTTING OF VALUES OF FLOW FOR VARIOUS ASSUMPTIONS OF TABLE 1 TO FIND THE POSITION OF THE NEUTRAL ZONE

parts of the building. Space does not permit the presentation of an example to show in detail how non-uniform temperatures may be handled.

Example of Application of Equation of Flow to an Actual Building

The foundry used for instructional purposes in the University of Michigan is located on the 4th floor of the East Engineering Building. The cross section and principal dimensions are represented in Fig. 7. A test was made one morning, while pouring was going on, the inflow and outflow of air being measured by anemometers at the openings. The area and vertical location of the openings in use are shown in Fig. 7. The average inside temperature was 59 deg., and the outside temperature, 20 deg. The openings were all on the leeward side of the building from the wind, so that the ventilation may be attributed to the temperature difference effect almost entirely. On this assumption, the flow can be calculated as in the previous example, and compared with the measured quantity.

In Table 3, the numbers in the first column, headed Z_A, represent the assumed distance of the Neutral Zone from the lowermost opening A (Fig. 7) for each trial. The distances to the other openings are shown in the next three columns. The flow is calculated for each opening for each trial position of the Neutral Zone, by means of equation (14).

Values of Q lying to the left of the heavy line in the Table represents inflow; those to the right, outflow.

TABLE 3. COMPUTED VALUES OF Q FOR VARIOUS POSITIONS OF NEUTRAL LEVEL Fig. 7

Z_A	Z_B	Z_C	Z_D	Q_A	Q_B	Q_C	Q_D	Total In	Total Out
12	7.5	10.5	12	135	200	202	36	135	438
14	5.5	8.5	10	146	171	183	33	146	387
16	3.5	6.5	8	156	137	160	29	157	326
17	2.5	5.5	7	161	116	147	27	161	290
18	1.5	4.5	6	166	90	133	25	166	248
19	.5	3.5	5	170	51	117	23	170	191
20	− .5	2.5	4	175	51	99	21	226	120
21	−1.5	1.5	3	179	90	77	18	269	95
22	−2.5	.5	2	183	116	44	15	299	59

The figures for total flow are plotted against the corresponding values of Z_A, to determine the position of the Neutral Zone that will represent equality of inflow and outflow. Figure 8 shows this work, and from it the Neutral Zone is found

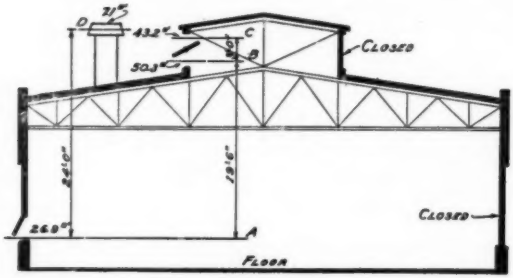

FIG. 7. SECTION THROUGH FOUNDRY AT UNIVERSITY OF MICHIGAN SHOWING AREAS AND VERTICAL DISTANCES

to lie 19 ft. 3 in. above the lower opening A, Fig. 7; and the flow is found to be 171 cu. ft. per sec., or 10,260 cu. ft. per min.

The actual flow as measured by the anemometers was found to be 12,500 cu. ft. per min. The agreement is within about 18 per cent, which is sufficiently close to show that the method of calculation is capable of practical use in predicting with some success, the flow of air resulting from temperature difference alone, in a simple building.

It is to be noted that the Neutral Zone lies only 3 in. below the lower opening of the monitor sash. The calculation is confirmed by the fact that at these openings the flow was observed to be generally out, but was at some times in, thus indicating an instability due to the near presence of the Neutral Zone.

Using the position of the Neutral Level as determined on Fig. 8, the flow for the several individual openings is found to be as follows:

Lower (sidewall) sash, opening A, Fig. 7, 171 cu. ft. per sec. *in*
Lower opening of monitor sash, B, Fig. 7, 36 cu. ft. per sec. *out*
Upper opening of monitor sash, C, Fig. 7, 113 cu. ft. per sec. *out*
Ventilator, opening D, Fig. 7, 22 cu. ft. per sec. *out*

Although the opening B, Fig. 7, is the largest of the four, it is not very effective in ventilation. The cause is to be found in the preponderance of area of upper

openings in use. There is a total of 100.6 sq. ft. of opening at the top against 26.9 sq. ft. below. As pointed out before, the most effective use of ventilating openings results from a nearly equal distribution of area of openings in upper and lower part of building.

Another test was made in this building, wherein the calculated results checked the observed within about 7 per cent.

Other Applications

In the foregoing examples, the objective has been to determine the flow from given data of temperature, vertical distances, and area of openings. It is apparent that, for given data regarding flow, temperatures, and vertical distances, the same principles can be employed to determine required areas. In some cases

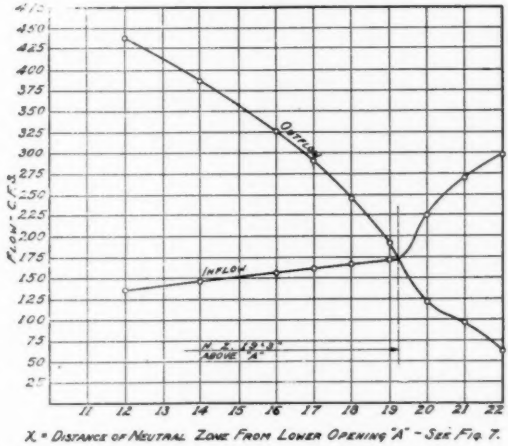

FIG. 8. PLOTTING OF VALUES OF INFLOW AND OUTFLOW FOR VARIOUS ASSUMPTIONS OF TABLE 3 TO FIND POSITION OF THE NEUTRAL ZONE

it may be required to maintain a specified temperature inside for some stated temperature outside, in order to determine the necessary openings for a sufficient amount of flow through a building to dispose of a known amount of heat, liberated in the processes housed. Problems of this kind can be solved satisfactorily with the assistance of the equations herein developed.

Temperature difference is of course not the sole natural agency operating to cause ventilation, inasmuch as the wind must always be reckoned with in more or less degree. To make a complete prediction of flow in any case, it is necessary to determine the heads at each opening caused respectively by the wind and temperature difference, add the two, and then calculate the flow by equation (16) which is the same as equation (8).

$$Q = \sqrt{\frac{h_t}{R}} \qquad (16)$$

where h_t is the *sum* of the heads caused by temperature difference and the wind.

The pressures or heads arising from the effect of the wind constitute another study and cannot be taken up here.

In a gravity hot-water system, or warm-air heating plant, it is evident that there must be a Neutral Zone somewhere within the vertical limits of the installation—a level at which the pressures in the cold and warm legs of the system are exactly equal. Problems of this kind are very difficult of solution because of the necessity of taking into account the friction head or resistances of the risers themselves. But the knowledge of the presence of a Neutral Zone—a place at which no cross flow can take place—and of the fact that its positions may be varied by the manipulation of resistances in the upper and lower part of the system, may often be helpful in a general way.

DISCUSSION

A. C. WILLARD: The Society owes a debt of thanks to Prof. Emswiler for this very able presentation of a very fundamental principle in both heating and ventilation. I don't believe that I have heard a paper that exceeds it in its importance in direct application to the advancement of the science of heating and ventilation in any meeting of the Society. I don't know whether Prof. Emswiler knows it or not, but his paper is of great interest to us in the field of warm-air gravity heating. The principles he has shown are fundamental to the operation of all gravity warm-air heating systems. They are, of course, fundamental in the determination of the in-leakages. The out-leakages which take place in a building are a result of the difference in temperature or density of the inside and outside air.

I congratulate the Society on having secured such a paper and congratulate Prof. Emswiler on the admirable presentation of such a complicated phenomenon as is shown here in a very direct and at the same time comprehensive application of these principles to specific examples. He has not only shown how the principles may be applied but he has checked up his results with actual tests in a practical building.

No. 739

SCOPE OF BUREAU OF MINES TUNNEL INVESTIGATIONS

By A. C. FIELDNER,[1] PITTSBURGH, PA.

NON-MEMBER

THE problem of the ventilation of vehicular tunnels was first brought to the Bureau of Mines by the late C. M. Holland, Chief Engineer of the New York and New Jersey State Bridge and Tunnel Commissions. They had a unique problem in designing the ventilation of this tunnel which extends between Jersey City and Lower New York under the Hudson River. It was the first vehicular tunnel in the world which was primarily for automobiles. In view of the probable traffic density engineers doubted whether it was possible to adequately ventilate tunnels under these conditions. As you know, automobile exhaust gas is asphyxiating. The dangerous constituent is carbon monoxide. Its concentration in the tunnel must at all times be kept so low by ventilation that no one will suffer any unpleasant effects in passing through the tunnel. This was the fundamental question that Mr. Holland put up to the Bureau of Mines. From our knowledge of mine ventilation we were certain that the tunnel could be adequately ventilated. It was necessary only to obtain certain fundamental data by experimentation in order to answer the following two questions, which we have termed Problems 1 and 2:

First, what is the amount and composition of the exhaust gas given off from automobiles when operating under conditions that would prevail in this tunnel?

Second, what is the maximum percentage of carbon monoxide allowable from a physiological standpoint in the atmosphere of this tunnel?

Two very clean-cut problems.

The series of articles which began with the January number of THE JOURNAL of your Society gives the complete report of the work done on these two problems. It is the first complete publication of the investigation.

The first problem was carried on at the Pittsburgh Experiment Station. A hundred and one automobiles and trucks were tested under actual conditions such as would prevail in the tunnel. No special adjustment of carburetors was made, but all machines were tested under conditions existing at the time they were received for test.

The tests were made over two courses each one mile in length. One of them was a level course and the other was on a three per cent grade to simulate the

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grades in the proposed tunnels. The Hudson River Vehicular Tunnels are over 8000 ft. long. Each of the two tubes have roadways 20 ft. wide so that two lines of traffic can go simultaneously in the same direction. Fig. 1 shows a truck that is arranged for determining the amount and composition of the exhaust gas by measuring the gasoline consumed and analyzing the exhaust gas.

Fig. 2 gives a summary of the results obtained at different speeds. The top curve shows the percentage of carbon monoxide. The next shows the gallons of gasoline used per hour, the bottom curve the cubic feet of carbon monoxide per hour. The points on the curves from left to right represent various speeds and conditions of operation, as idling, racing, going down grade 15 mi. per hour, 10 mi. per hour, and 3 mi. per hour, respectively, etc. The solid lines represent averages for seven-passenger touring cars; the broken lines averages for five-passenger touring cars, and the dotted line for one-ton trucks.

FIG. 1. TRUCK ARRANGED FOR DETERMINING AMOUNT AND COMPOSITION OF EXHAUST GAS

An interesting conclusion from inspecting the curves is that the cubic feet of carbon monoxide per hour is directly proportional to the gallons of gasoline consumed per hour, which means that changes in the proportion of carbon monoxide in the exhaust gas is of less moment than the total amount of exhaust gas produced. Thus the greatest evolution of carbon monoxide is when the cars are accelerating up a three per cent grade. From these tests tables have been prepared giving the number of cubic feet of carbon monoxide produced per hour by various types of passenger cars and various sizes of trucks at speeds ranging from 6 to 20 mi. per hour on level and on grades.

These data serve as a basis for calculating the air required for the ventilation.

The second problem on the physiological effect of exhaust gases was conducted by Dr. Yandell Henderson, consulting physiologist of the Bureau of Mines, at Yale University. Dr. R. R. Sayers, Chief Surgeon of the Bureau, who later took charge of the physiological side of the investigation is here and will speak to you on problem two.

The third phase of the tunnel investigations was the determination of the coefficient of friction and power required for passing the required amount of air through

the concrete ducts of the tunnel. This problem was in charge of Prof. A. C. Willard at the University of Illinois, and the experimental work was conducted there.

After these three questions were answered, *viz.:* First, the amount of carbon monoxide given off by automobiles; Second, the maximum percentage of carbon monoxide allowable in tunnel atmospheres; and third, the power requirements for moving the air through the ducts and tunnel, and the design of the ducts—then it was desired to check and correlate all this data in an experimental tunnel of one-fourth size. You saw the motion picture this morning which described these experiments. The experimental tunnel was built in our experimental mine

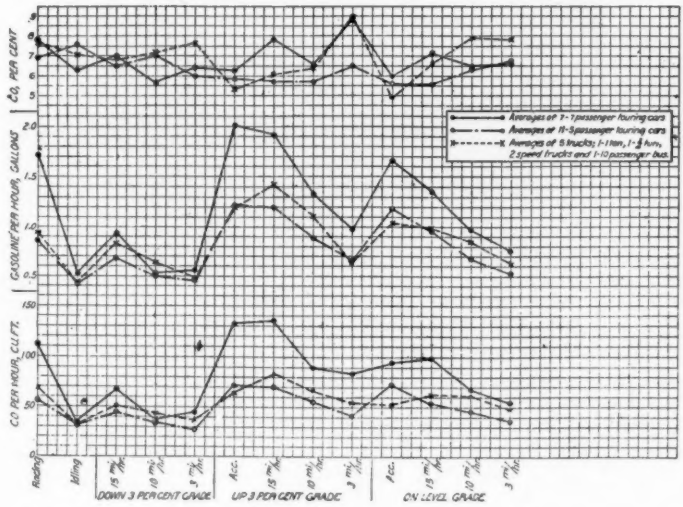
CO, PER CENT
GASOLINE PER HOUR, GALLONS
CO PER HOUR, CU. FT.
Averages of 7-7 passenger touring cars
Averages of 11-5 passenger touring cars
Averages of 5 trucks; 1-1 ton, 1-3 ton, 2 speed trucks and 1-10 passenger bus
Racing
Idling
15 M.P.H.
10 M.P.H.
5 M.P.H.
Acc.
DOWN 3 PER CENT GRADE
UP 3 PER CENT GRADE
ON LEVEL GRADE

FIG. 2. CHART SHOWING SUMMARY OF RESULTS OBTAINED IN EXHAUST GAS TESTS

near Pittsburgh, Pa. The tunnel was in the form of an underground oval track 400 ft. around. Eight Ford cars were operated in it simultaneously at a speed of about 10 mi. per hour. Samples of the atmosphere from the tunnel were taken at different points in eight cross sections of the tunnel. These were analyzed for carbon monoxide. Also physiological observations were made on the men. Different types of ventilation were tried; First, introducing the air at the bottom of the tunnel and exhausting it at the top; Second, introduction of the fresh air at the top of the tunnel and exhausting it at the bottom; and several other combinations to determine which was the most economical and efficient method of transverse ventilation.

The experimental tunnel experiments checked the data obtained in the first three problems.

The Bureau went into this investigation primarily because it would furnish basic data for tunnel ventilation in general, including the problem of removal of carbon monoxide. The results of the investigation were used in ventilating

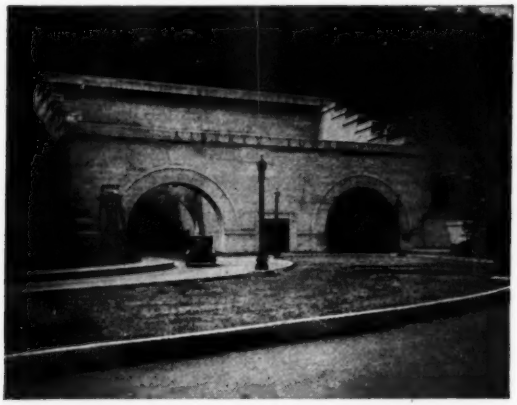

FIG. 3. ENTRANCE TO LIBERTY TUNNELS, PITTSBURGH, PA.

the Liberty Tunnels at Pittsburgh. These two tunnels penetrate the South Hills near the Monongahela River. They are 6000 ft. long and have a cross sectional area of 468 sq. ft. Not being under water it was practical to make larger tunnels and to ventilate them by a longitudinal system of ventilation, combined with one vertical exhaust shaft at the middle of the tunnels.

Fig. 3 shows the entrance to the tunnel and Fig. 4 the fan house at the top of the hill over the middle of the tunnels. These fans exhaust the air from the first half of the tunnel and blow air down the shaft through a nozzle into the second half of the tunnel, the air direction being with the traffic.

Because it was desirable to have a means of determining continuously the percentage of carbon monoxide in the exhaust air from the tunnel we started de-

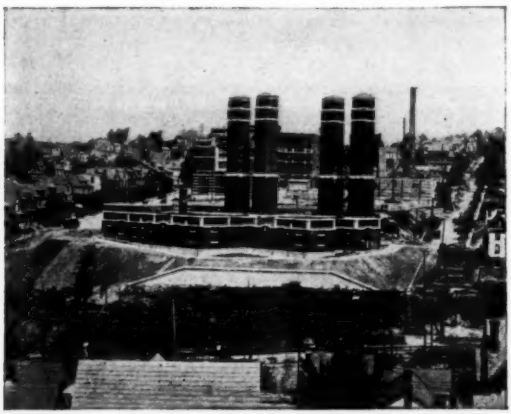

FIG. 4. FAN HOUSE OVER MIDDLE OF LIBERTY TUNNELS

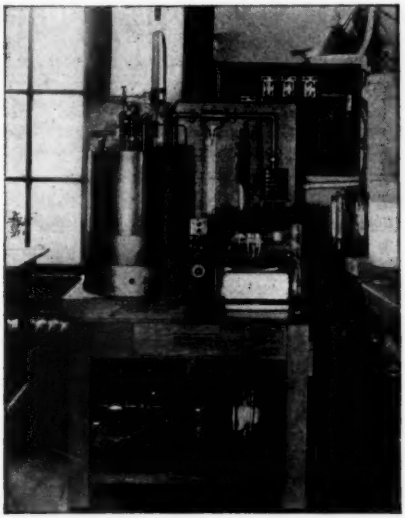

FIG. 5. CARBON MONOXIDE RECORDER IN FAN HOUSE OF LIBERTY TUNNELS

velopment work at the Pittsburgh Station on a continuous analyzing and recording device which should determine and record carbon monoxide to an accuracy of one part in a hundred thousand. As the allowable limit for tunnel ventilation is

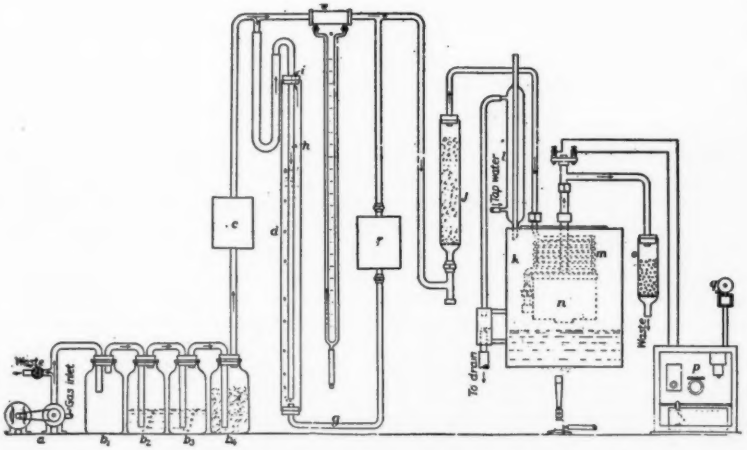

FIG. 6. DIAGRAMMATIC SKETCH OF CO_2 RECORDER

set at four parts in 10,000, it was desired to keep actual records one decimal point farther. Such an apparatus was successfully built after one year's painstaking experimental work and was put in the fan house of the Liberty Tunnels. It was operated over a period of six months with entire satisfaction.

Fig. 5 is a picture of the recorder in the Liberty Tunnels. You may be interested in this apparatus because it has a great many uses in connection with carbon monoxide problems. It gives a continuous record on the chart of a standard Leeds & Northrup potentiometer, of percentage of carbon monoxide with an accuracy of one part in 100,000. That is one-thousandth of a per cent. The principle of the apparatus is measurement of the heat generated by the oxidation of

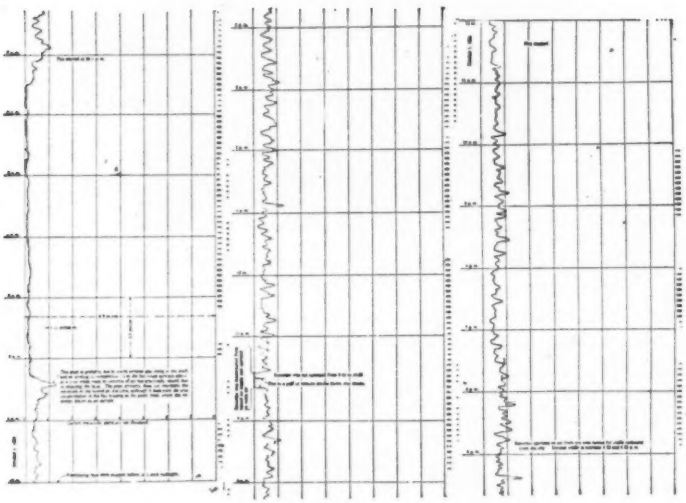

FIG. 7. CHART OF TYPICAL DAY'S OPERATION AT LIBERTY TUNNELS

carbon monoxide to carbon dioxide in the presence of a catalytic material known as hopcalite (oxides of copper and manganese). Multiple thermocouples register the increase of heat from the oxidation of the carbon monoxide. In operation, a continuous current of approximately one cubic foot of air per minute is drawn through the apparatus.

Fig. 6 is a diagrammatic sketch of the apparatus. The air from the tunnel is pumped through purifiers of sulphuric acid and glass wool, then through a canister of charcoal to take out unburned gasoline vapor, through an orifice flowmeter to keep the flow constant, through a final drying agent of calcium chloride and then through the catalytic cell in the water bath. Fig. 7 is a typical chart of a day's operation of the Liberty Tunnels at Pittsburgh. You will notice that the concentration of carbon monoxide has been kept less than one part in 10,000 This apparatus has been found very useful in testing stoves for CO in products of combustion, and may find use in connection with the ventilation of garages.

SUMMARY OF RESULTS OF TUNNEL INVESTIGATIONS

By Dr. R. R. Sayers[1]

Mr. Fieldner has outlined the problem with which the physiologists and medical men were concerned, as well as the large number of chemists who were engaged in this work. He has also told that Dr. Henderson carried out the first study on this problem.

Ventilation, as defined by this Society, is the process by which vitiated air of an inclosed or partly inclosed space is continuously replaced by fresh air; fresh air may be defined as invigorating pure air; pure dry air, at sea level, contains about 20.94 per cent oxygen and 0.03 per cent carbon dioxide. The word *invigorating* will be noticed in the definition: this means that the air must be cool and stimulating—that is what invigorating means.

Some years ago, carbon dioxide was used as an index of the vitiation of air, that is, of the vitiation due to the metabolism of man. This does not mean that the air was thought unfit to breathe on account of the carbon dioxide, because it is doubtful whether very many men believed that carbon dioxide was the cause of the deleterious effects experienced in a room the air of which was so vitiated. Then for a time the organic material accompanying carbon dioxide was suspected as being the cause. Later, this theory was proved to be a myth and it was found that the untoward effects on the comfort and efficiency of those so exposed were due to increased temperature and humidity.

Mr. Fieldner has indicated that carbon monoxide was the index used in the tunnel investigations carried out by the Bureau of Mines, and that it should be the index of the vitiation of the air in many industries where it is the most dangerous gas in low concentrations.

Carbon monoxide exerts its extremely dangerous action on the body by displacing the oxygen from combination with the hemoglobin. Hemoglobin, the coloring matter of the blood, normally absorbs oxygen from the air and delivers it to the tissues through the blood. The affinity of CO for hemoglobin is about 300 times that of oxygen. Because of this, even when only a small amount of the poisonous gas is present in the air breathed into the lungs, much of the hemoglobin is locked up in combination with CO and so cannot keep up its usual work of carrying oxygen to the tissues. These, because of lack of oxygen, cannot do their work properly. If they are smothered long enough, the tissue cells become damaged and the injury to the cells may be permanent even if the patient survives.

At the conclusion of his studies, Dr. Henderson advised that if the Holland vehicular tunnel were so constructed that persons passing through would be exposed to not more than 4 parts of CO in 10,000 parts of air (0.04 per cent) for not longer than 45 min., they would experience no ill effects. The Bureau of Mines confirmed these findings and continued its studies on the effects of long exposures to low concentrations, the effect of strenuous exercise, and the effects of high temperatures and humidities in low concentrations. Following is a summary of the Bureau's results:

With the subject at rest

Exposure for 6 hr. to 2 parts of CO in 10,000 caused—

a. Saturation of 16 to 20 per cent of the hemoglobin of the blood with CO.
b. Very mild subjective symptoms of CO poisoning at the end of the test.
c. No noticeable effects after the test.

[1] Chief Surgeon, U. S. Bureau of Mines Experiment Station, Pittsburgh, Pa.

Exposure to 3 parts of CO caused—

a. Saturation of 22 to 24 per cent of the hemoglobin with CO after 4 hours, and 26 to 27 per cent after 5 hours.
b. Symptoms at the end of 2 hours absent; after 4 hours, mild effects attributed to CO poisoning; and after 5 hours, moderate effects.
c. After-effects of 4 hours' exposure mild; of 5 hours' exposure, moderate.

Exposure to 4 parts of CO in 10,000 caused—

a. Saturation of 15 to 19 per cent of the hemoglobin with CO at the end of 1 hour, and 21 to 28 per cent at the end of 2 hours.
b. After-effects, moderate to marked.

With the subject exercising strenuously

Exposure for 1 hour to 2½ parts of CO in 10,000 caused—

a. Saturation of 14 to 16 per cent of the hemoglobin with CO.
b. Moderate symptoms of CO poisoning at the end of the test.
c. After-effects, mild to moderate.

Exposure for 1 hour to 3.3 parts of CO in 10,000 caused—

a. Saturation of 17 per cent of the hemoglobin with CO.
b. Mild to moderate symptoms of CO poisoning.
c. After-effects, mild to moderate.

Exposure for 1 hour to 4 parts of CO in 10,000 caused—

a. Saturation of 23 per cent of the hemoglobin with CO.
b. Moderate symptoms of CO poisoning.
c. Moderate after-effects.

With the subject at rest, temperature and humidity high.

Exposure for 1 hour to 3.1 parts of CO in 10,000 caused—

a. Saturation of 16 per cent of the hemoglobin with CO.
b. Mild symptoms of CO poisoning.
c. Mild to moderate after-effects.

A diagnosis of CO poisoning is usually made from a correlation of the history and place of possible exposure with the symptoms produced. But this is not always positive evidence, because CO exists at unsuspected places, and the symptoms produced are common to other causes. The only infallible test is by examining the blood for carbon monoxide hemoglobin, for which many methods have been devised. The Bureau in its studies developed a number of methods for determining CO. The iodine pentoxide method for the determination of CO in the air was developed further and an especially interesting phase of this was the freezing out of gasoline and unburned vapors by liquid air. For the diagnosis of CO poisoning a method using the spectrophotometer was perfected. By this method an accurate determination could be made in a very short time and from as little as 0.1 cubic centimeter of blood. While accurate, an expensive apparatus is required and the method is not suitable for field work. Another test developed is known as the pyrotannic acid method. By its use a small amount of blood (0.10 cc., which can be procured from a puncture wound in the finger) can be quantitatively examined in a few minutes for CO and a true diagnosis made. The apparatus is portable (pocket size), and the technique for use is sufficiently easy for unskilled users to make an accurate diagnosis, as well as to determine later when the CO has been removed.

The chief factors in preventing poisoning by carbon monoxide are:

1. Good ventilation, as this will dilute and carry away the gas;
2. Avoidance as much as possible of any exposure to air known to contain CO;

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3. Use of adequate protective equipment when atmospheres known to contain CO are to be encountered; keeping calm when necessary to enter or be exposed unprotected to atmospheres containing it, not hurrying but getting to fresh air as quickly, and with as little exertion, as possible.

The steps in effective treatment of acute poisoning by CO are:

1. The victim should be removed to fresh air as soon as possible.

2. If breathing has stopped, or is weak and intermittent, or present in but occasional gasps, artificial respiration by the Schaefer method should be given persistently until normal breathing is resumed, or until after the heart has stopped.

3. Circulation should be aided by rubbing the limbs and keeping the body warm with blankets, hot-water bottles, hot bricks or other devices, care being taken that these are wrapped or do not come in contact with the body and produce burns. This aids in tiding the body over a period of low vitality. Other stimulants, such as hypodermics of caffeine, sodium benzoate, or camphor in oil, should not be administered except by a doctor after he has considered the possibility of over-stimulation and consequent collapse.

4. The patient should be kept at rest, lying down in order to avoid any strain on the heart. Later, he should be treated as a convalescent and given plenty of time to rest and recuperate.

5. After-effects of poisoning by carbon monoxide should be treated symptomatically.

6. It should be emphasized that inhalations, for a period of 20 to 30 min. of oxygen, or a 5 per cent mixture of carbon dioxide in oxygen if available, will when given immediately greatly lessen the number and severity of symptoms of carbon monoxide poisoning, as well as decrease the possibility of serious sequelae. All industries in which this type of poisoning commonly exists should provide apparatus (inhalers) for the efficient administration of these treatments. This apparatus should be placed at points most convenient for treating carbon monoxide poisoning, and employees trained in its use so that resuscitation may be effected immediately.

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No. 740

ADVANTAGES OF HEAT INSULATION IN HOTELS, APARTMENT HOUSES, AND PRIVATE RESIDENCES

By R. H. HEILMAN,[1] PITTSBURGH, PA.

MEMBER

Introduction

IT HAS become increasingly evident from the experimental results obtained during the course of the writer's researches at Mellon Institute[2] that an opportunity exists for applying much of the knowledge gained in demonstrating the economic advantages of the use of heat insulation in hotels, apartment houses and private residences.

The value of appropriate pipe coverings in industry is recognized, and because of this fact investigational work is now being centered on the development of special types of heat-insulating materials for specific plant requirements.

With respect to residential buildings, however, it is clear that little attention has been accorded to the practical utilization of existing knowledge regarding insulation of boilers, hot-water supply systems, and heating installations.

In this paper the writer will endeavor to provide data that will be helpful to the heating engineer in selecting as well as in directing the use of suitable heat insulation.

General Description of Heat-Insulation Materials

There are three types of commercial heat insulations available which can be used to insulate low and medium temperature lines. These types may be classified as follows:

1. *Corrugated Type.* This type consists of alternate layers of plain and corrugated asbestos paper wound upon a mandrel and firmly bound together. Examples of this type are Air Cell covering, containing four corrugations to the inch, and Carocel covering, which has eight corrugations to the inch.

2. *Moulded Type.* The well-known 85 per cent magnesia covering illustrative of this type is manufactured by moulding a mix of approximately 85 per cent magnesium carbonate and approximately 15 per cent asbestos fiber into blocks and cylindrical shapes, and then planing the dried material to true dimensions.

3. *Laminated Type.* This type consists of layers of asbestos paper wound upon a mandrel and firmly bound together, each successive layer of paper being partly sepa-

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[1] Senior Industrial Fellow, Mellon Institute of Industrial Research, University of Pittsburgh, Pittsburgh, Pa.

[2] See, in this connection, the following contributions of the writer:
Heat Losses from Bare Pipes, *Trans. A.S.M.E.*, vol. 44 (1922), p. 309;
Heat Transmission from Bare and Insulated Pipes, *Ind. Eng. Chem.*, vol. 16 (1924), p. 451;
Heat Losses through Insulating Materials, *Mech. Eng.*, vol. 46 (1924), p. 593;
Insulation of Superheated Steam Surfaces, *Chem. Met. Eng.*, vol. 31 (1924), p. 934; and
Insulation of Domestic Hot Water Tanks, *Sanitary & Heating Eng.*, 102 (1924), No. 11, p. 370.

Paper presented at Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Buffalo, N. Y., January, 1926.

rated from the next adjacent layer by means of mechanically made indentations in the asbestos paper (Multi-Ply Construction) or by means of small quantities of organic or spongy material placed between the layers of paper (Asbesto-Sponge Felted construction).

Evaluation of Heat-Insulation Materials

The most important general requirements of a good heat-insulating material are as follows:

1. *Low heat conductivity* at the temperature to which the insulation is to be subjected. The fact that an insulation has a very low conductivity at low temperatures does not necessarily prove that it is a good insulator at high temperatures. In order to ascertain the suitability of a given insulation, it is necessary to have a conductivity

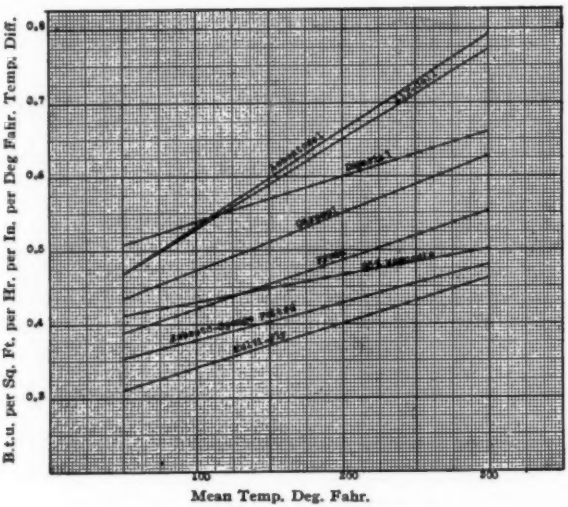


FIG. 1. THERMAL CONDUCTIVITY

curve of the material as a function of the temperature, so as to be able to determine exactly the conductivity of the material at the given specified temperature.

2. *Low Specific Heat.* Where the covering is to be placed on a steam line under continuous operating conditions, the value of the specific heat of the insulation is of little importance; but where the insulation is placed on an oven, for example, which is used only several hours per day, the value of the specific heat of the insulation is often more important than the thermal conductivity of the insulation.

3. The covering should have sufficient *resistance to the effects of heat* to be able to withstand any temperature to which it is to be subjected. While this quality is of great importance in industry, when high temperatures prevail and when often a sacrifice has to be made in thermal conductivity to obtain a covering which will withstand severe temperature conditions, it is also of importance in low-temperature insulation, where an architect may specify for a heating installation some organic type of material which is suitable only for very low temperatures.

4. The covering should have sufficient *mechanical strength* to withstand vibration and accidental knocks. A smooth, even surface is often of prime importance in maintaining high heat insulating efficiency by eliminating cracked and broken sections.

The thermal conductivity of various types of insulation has been determined experimentally by the writer and the results are shown in Fig. 1, wherein the thermal conductivity of the material is plotted as a function of the mean temperature between the two surfaces of the insulation. The curves shown are the average results of approximately ten tests on each type of insulation.

Anyone of these coverings is satisfactory for insulating heating systems. All of them are made of materials that will successfully withstand the effect of any temperature that is encountered in heating practice. It will be observed, however, that some materials are much more efficient than others. If the cost of the materials were the same in each case, the selection of the proper material to use would be obvious. But since the costs are not identical, the engineer or purchaser may be in doubt as to which covering to select, because he ordinarily has no way of determining the relative merits of efficiency and cost of insulation.

The following section presents data and examples that will enable the engineer to determine the type of insulation he should use in any given case.

Economic Considerations

Probably the most important item in selecting insulation for a given case is the determination of the heat loss through the various insulations for the conditions under which they are to operate; namely, temperature difference, pipe size, etc.

In order to calculate accurately the loss of heat through a given insulation from the thermal conductivity of the insulation, it is absolutely necessary that the temperature of the outer and inner surfaces be known.

The temperature at the inner surface of the covering can for engineering purposes be taken as the temperature of the pipe. Since practically all commercial coverings have canvas jackets, the temperature of this jacket or the outer surface temperature of the covering can be determined from Equation 1 or 2, determined experimentally by the writer.[3]

$$Td = \frac{272.5h}{h + \frac{564}{D^{0.19}}} \quad \ldots\ldots(1)$$

$$h = \frac{564Td}{D^{0.19}\,(272.5 - Td)} \quad \ldots\ldots(2)$$

Td = temperature difference between canvas surface and room, deg. fahr.
h = total B.t.u. loss per hr. per sq. ft. of canvas-surface
D = outer-surface diameter, in in.

The heat loss through the pipe covering can then be determined from the equation.

$$H = \frac{K(T_1 - T_2)}{r_1 \log_e \frac{r_2}{r_1}} \quad \ldots\ldots(3)$$

H = total B.t.u. loss per hr. per sq. ft. of pipe surface
K = conductivity of covering at mean of two surface temperatures
= conductivity at $\frac{T_1 + T_2}{2}$
r_1 = radius of pipe or inner radius of covering
r_2 = outer radius of covering

[3] *Trans. A.S.M.E.*, vol. 44 (1922), p. 309.

Probably the simplest way to solve Equation 3 is to make an assumption of the outer-surface temperature T_2, and then from the conductivity curve (Fig. 1) determine the conductivity of the material at the mean of the surface temperature assumed and the inner surface temperature. The loss through the covering should then be calculated for the assumed outer-surface temperature, and this loss should be checked against the loss as obtained from the surface-loss equation. If the two losses do not check, the assumed outer-surface temperature must be changed according to the indications of the calculation and the process repeated until the two losses or the outer surface temperatures check. With the aid of a slide rule, one will find that the heat loss through a covering can be calculated accurately in a very short time.

In most cases where extreme accuracy is not necessary, however, the loss of

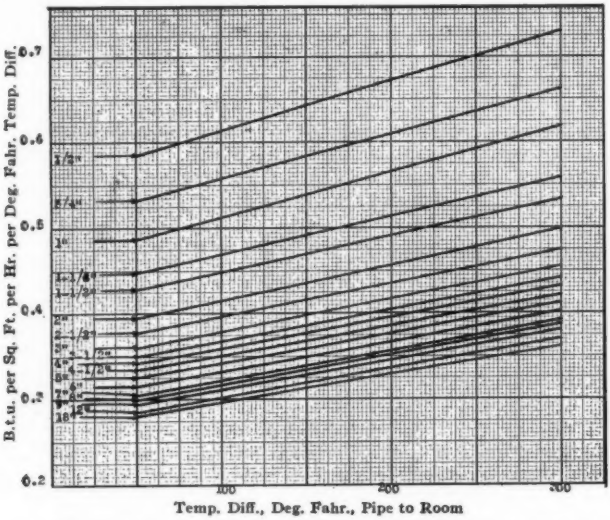


FIG. 2. HEAT LOSS THROUGH 1" THICK MULTI-PLY COVERING

heat through any of the insulations whose conductivity curves are shown in Fig. 1, for any thickness of covering and for any temperatures generally used in heating practice, can be obtained from Table 1 and Figs. 2, 3 and 4.

In these curves the unit loss through 1-, $1^1/_2$-, and 2-in. thick Multi-Ply is given for temperature differences up to 300 deg. fahr. The loss through other thicknesses can be obtained from the curves by interpolation.

Table 1 gives the factor by which the loss through Multi-Ply covering must be multiplied to give the loss through any of the coverings tested.

The process will be illustrated by an example. Determine the heat flow in B.t.u. per hr. per sq. ft. of pipe surface through a Carocel covering 1 in. thick on a 2 in. pipe. The temperature of the pipe is 220 deg. fahr. and the room temperature 70 deg. fahr.

The loss through Multi-Ply covering 1-in. thick on 2-in. pipe at 150 deg. fahr.

temperature difference = 0.435; the factor for Carocel at 150 deg. fahr. temperature difference = 1.345; then the heat loss through Carocel = 0.435 × 1.345 × 150 = 87.8 B.t.u. per sq. ft. of pipe surface per hour. It will be found that values obtained by this method will be within 2 per cent of the correct values as obtained from the thermal conductivity curves.

The saving resulting from the use of a given insulation equals the heat loss from the bare pipe less the heat loss from the covered pipe.

The unit heat loss from various size pipes under various temperature conditions

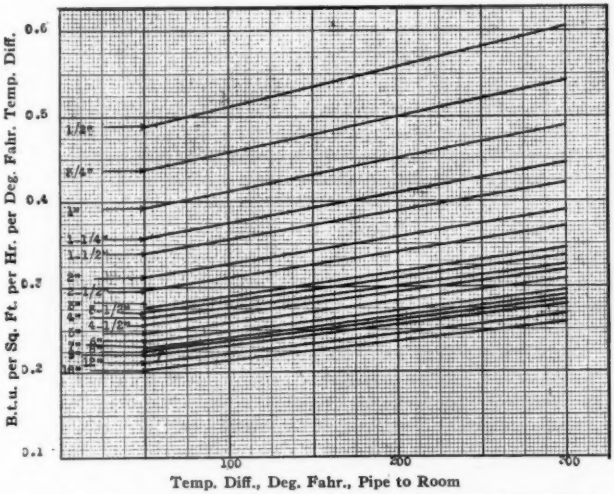


FIG. 3. HEAT LOSS THROUGH 1½" THICK MULTI-PLY COVERING

is given in Fig. 5. The total heat loss from various size pipes can be expressed approximately by Equations 4 and 5.

$$H = 3320 \frac{77 + Td - 103D^{0.11}}{103D^{0.11} - Td + 1020} \quad \ldots\ldots (4)$$

$$Td = \frac{H - 250}{0.00098H + 3.25} + 103D^{0.11} \quad \ldots\ldots (5)$$

The heat loss in B.t.u. per lineal foot of pipe, in pounds of coal, and in dollars and cents for various pipe sizes under various operating temperatures, is given in Table 2.

The loss varies from $0.53 per 100 lineal feet of 0.5-in. pipe at 120 deg. fahr., to $76.50 per 100 lineal feet of 18-in. pipe at 350 deg. fahr.

It is believed that, if the actual saving in fuel that can be effected by the proper use of insulation could in some way be impressed upon the public, a great amount of fuel, entirely wasted each year, could be saved. Even in the present era of constantly increasing efficiencies and conservation there are thousands of homes and small plants which use no insulation whatsoever. In practically every case

where insulation is employed it can be shown that the insulation will pay for it self in a period of one year or less. For high-temperature conditions, such as are used in chemical processes, the insulation will often pay for itself in a period of one month.

Saving by Insulating

The following examples illustrate what can be expected in the way of savings and time required to pay for the installation in a practical case for low-temperature insulation.

Conditions: One and one-half (1.5) in. pipe at 220 deg. fahr. temperature with a room temperature of 70 deg. fahr., or a temperature difference of 150 deg.

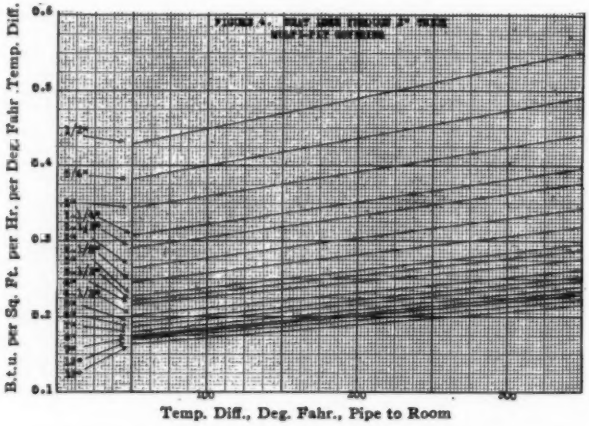


FIG. 4. HEAT LOSS THROUGH 2" THICK MULTI-PLY COVERING

fahr. between the pipe surface and the surrounding air. The time required to pay for the insulation and the savings per year when the pipe is insulated with 1-in. thickness of insulation and steam is flowing through the pipes 6 months in each year.

The pipe is to be insulated successively with Air Cell, Carocel, 85 per cent Magnesia, and Multi-Ply covering.

The heat loss per lineal foot of bare 1.5-in. pipe per hr. = 396 × 0.498 = 197 B.t.u.

The heat loss through 1-in. thickness of Air Cell covering per lineal foot per hr., from Fig. 2 and Table 1, = 53.7 B.t.u. per hr. The saving per hour over that lost from the bare pipe = 197 — 53.7 = 143.3 B.t.u.

Assuming that the useful heat generated by the fuel costs 60 cents per 1,000,000 B.t.u., the saving in dollars and cents for a 6 mo. period = $\frac{143.3 \times 4380 \times 0.60}{1{,}000{,}000}$ = $0.377 per lineal foot. Assuming that the cost of application of the covering is 20 per cent of the list price and that the cost of the covering itself is 30 per cent of

the list price, the actual cost of the covering installed is then from Table 3, $0.50 \times 0.33 = \$0.165$ per lineal foot. It will therefore take $\frac{0.165}{0.377 \times 2} = 0.218$ year, or 2.62 mo., for the Air Cell insulation to pay for itself.

By similar calculation it will be found that the saving for Carocel insulation = $0.397 per lineal foot.

Assuming that the cost of installing the covering is 20 per cent of the list price

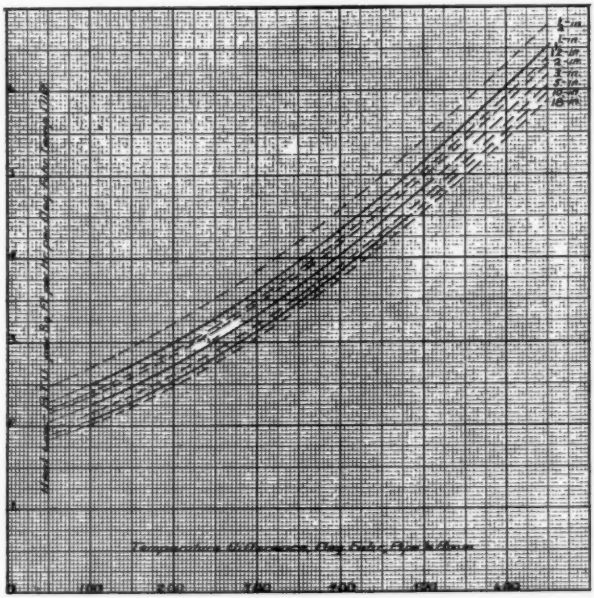


FIG. 5. BARE PIPE LOSSES

and that the cost of the covering itself is 35 per cent of the list price, the actual cost applied $= 0.55 \times 0.33 = \$0.181$ per lineal foot. It will, therefore, take $\frac{0.181}{0.397 \times 2}$ or 0.23 year, or 2.76 mo., for the Carocel insulation to pay for itself.

With the cost of Magnesia covering at 45 per cent of list price, it will require 3.17 mo. for it to pay for itself. With the cost of Multi-Ply covering at 65 per cent of list price, it will take it 3.95 mo. to pay for itself.

From these considerations it is evident that the lowest priced covering pays for itself sooner than the higher priced covering. This is not an indication, however, that the lowest priced covering is the most economical to use; in fact, it will be found that the opposite is true.

The writer has knowledge of one hotel where approximately 90,000 lineal feet of Air Cell pipe covering was used in addition to the flat block insulation. This installation is mentioned as an interesting example of what could be expected

by covering the pipes successively with Air Cell, Carocel, 85 per cent Magnesia, and Multi-Ply insulation. For comparative purposes, it will be assumed that the piping is all of $1^1/_2$ in. pipe, with the temperature of the pipe at 220 deg. fahr. and an air temperature of 70 deg. fahr. It will also be assumed that the cost of installing the covering is 20 per cent of the list price in each case. The actual cost of the material is taken as follows:

Air Cell, list minus 70 per cent;
Carocel, list minus 60 per cent;
Magnesia, list minus 55 per cent; and
Multi-Ply, list minus 35 per cent.

There will then be had for 90,000 lineal feet of covering 1-in. thick, operating

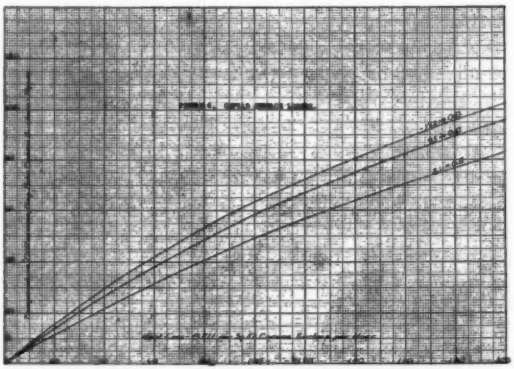


FIG. 6. CANVAS SURFACE LOSSES

6 months of the year, the following data:

Covering	Cost Installed	Months Required to Pay for Itself	Saving per Mo.
Air Cell	$14,850	2.62	$5660
Carocel	$16,350	2.76	$5912
85% magnesia	$19,300	3.14	$6140
Multi-Ply	$25,250	3.95	$6390

From these calculations it will be seen that it will take approximately 1 year of operation before the increased saving due to using Carocel covering instead of Air Cell covering will pay for the extra first cost of the Carocel covering. Similarly it will take approximately 1.5 years for magnesia covering and approximately 2.5 years for Multi-Ply covering to pay for the extra first cost over the first cost of the Air Cell covering for the same installation.

If, however, magnesia is taken as an example, at the end of 1.5 years the income from the magnesia installation will be $2880 a year greater than the income from the Air-Cell insulation. Similarly, at the end of 2.5 years the income from the Multi-Ply covering will be $4380 a year greater than the income from the Air Cell installation.

In this installation it has been assumed that all of the heat lost through the bare

or the covered pipe is a total loss. The writer is aware of the fact that this is not so in most practical cases, for some of the heat is not wasted. For example, in a private residence some of the heat lost to the basement will penetrate through the floor and into the rooms above; likewise some of the heat lost from the pipes in a hotel will penetrate through the walls into the rooms. There is no question, however, that a large percentage of this heat would be actually wasted.

TABLE 1. PIPE-COVERING FACTORS

	Temperature Difference			Pipe to Air		Deg. Fahr.
Type of Covering	50	100	150	200	250	300
85% Magnesia	1.225	1.207	1.198	1.163	1.152	1.133
Asbesto-Sponge Felted	1.048	1.045	1.042	1.038	1.032	1.033
Imperial	1.533	1.515	1.496	1.474	1.460	1.441
Carocel	1.354	1.349	1.344	1.340	1.338	1.333
Pyrex	1.205	1.200	1.195	1.196	1.182	1.186
Air Cell	1.505	1.520	1.535	1.550	1.565	1.580
Asbestocel	1.515	1.535	1.554	1.565	1.592	1.610

It is evident, therefore, that all exposed piping should be adequately insulated, the type and thickness of covering to use depending upon the steam temperature, fuel cost, insulation cost, expected life of installation, and a few other factors of less importance.

Economic Thickness of Insulation

The heating engineer is often confronted with the question, what thickness of insulation should be used for a specific case? While this is a very important query the answer is not readily obtainable, as considerable calculation is necessary to solve this economic problem. For the convenience of architects and heating engineers, the economic thickness curves and the methods used in obtaining them are given in this paper for four types of insulation.

Since the result desired is the maximum net saving of money for any given condition, it is necessary to know the total yearly operating expenses of the covered line. Having obtained these expenses for various thicknesses of covering for a given pipe size and a given fuel cost at a specified temperature, obviously the most economic thickness of covering to use would be that thickness that gave the lowest total yearly operating expenses.

The total yearly operating expenses consist of the annual cost of the heat lost through the covered line and the annual fixed charges on the cost of the covering itself.

Annual Operating Expenses

The annual operating expenses or the annual cost of the heat loss through the covering has been calculated for Air Cell, Carocel, 85 per cent magnesia, and Multi-Ply coverings, for various thicknesses, on $^3/_4$ in., $1^1/_2$ in., 3 in., and 6 in. pipe and flat surfaces, at temperature differences of 100, 200 and 300 deg. fahr. between pipe surface and surrounding air, for a steam cost of $0.20 per 1,000,000 B.t.u.

The operating costs for various thicknesses of Carocel covering for 1.5-in. pipe are shown in Fig. 7. For example, the heat loss through 2-in. thick Carocel covering at 200 deg. temperature difference from Fig. 4 and Table 1 = 89.5 B.t.u.

TABLE 2. LOSSES FROM HORIZONTAL BARE IRON STEAM PIPES

From 100 lineal feet of pipe per mo. of 30 days with steam in pipes 24 hours per day. Coal at $4.00 per ton of 2000 lb.

Gage Press	Hot Water			Hot Water			Hot Water			Hot Water			10 Lbs.			80 Lbs.			120 Lbs.		
Temp.	120 deg. fahr.			150 deg. fahr.			180 deg. fahr.			210 deg. fahr.			239.4 deg. fahr.			324 deg. fahr.			350 deg. fahr.		
Pipe Size	Dollars Loss	Pounds Coal	B.t.u. per lineal ft. per deg. fahr. Diff. per Hr.	Dollars Loss	Pounds Coal	B.t.u. per lineal ft. per deg. fahr. Diff. per Hr.	Dollars Loss	Pounds Coal	B.t.u. per lineal ft. per deg. fahr. Diff. per Hr.	Dollars Loss	Pounds Coal	B.t.u. per lineal ft. per deg. fahr. Diff. per Hr.	Dollars Loss	Pounds Coal	B.t.u. per lineal ft. per deg. fahr. Diff. per Hr.	Dollars Loss	Pounds Coal	B.t.u. per lineal ft. per deg. fahr. Diff. per Hr.	Dollars Loss	Pounds Coal	B.t.u. per lineal ft. per deg. fahr. Diff. per Hr.
1/4"	0.53	215	0.543	0.90	363	0.573	1.32	526	0.605	1.77	707	0.638	2.24	897	0.670	3.92	1566	0.779	4.51	1805	0.815
3/4"	0.65	261	0.660	1.09	437	0.690	1.58	635	0.729	2.11	845	0.762	2.70	1083	0.809	4.74	1895	0.943	5.48	2190	0.990
1"	0.78	313	0.791	1.31	525	0.829	1.91	763	0.878	2.55	1020	0.920	3.26	1305	0.973	5.72	2290	1.14	6.25	2601	1.18
1 1/4"	0.97	388	0.979	1.61	646	1.02	2.36	947	1.087	3.19	1275	1.15	4.00	1610	1.20	7.14	2860	1.42	8.18	3280	1.48
1 1/2"	1.08	432	1.09	1.82	728	1.15	2.65	1060	1.220	3.57	1430	1.29	4.54	1818	1.35	7.98	3190	1.58	9.28	3710	1.67
2"	1.32	530	1.34	2.21	886	1.40	3.24	1297	1.491	4.37	1750	1.58	5.36	2142	1.60	9.78	3910	1.94	11.37	4549	2.05
2 1/2"	1.56	625	1.58	2.64	1056	1.67	3.86	1545	1.778	5.18	2075	1.87	6.65	2660	1.98	11.66	4660	2.32	13.66	5460	2.46
3"	1.86	744	1.88	3.15	1260	1.99	4.56	1824	2.100	6.12	2460	2.22	8.24	3292	2.46	13.88	5550	2.76	16.14	6450	2.91
3 1/2"	2.11	843	2.13	3.54	1418	2.24	5.18	2070	2.380	6.95	2780	2.51	8.89	3554	2.65	15.82	6325	3.14	18.31	7322	3.30
4"	2.33	934	2.36	3.95	1580	2.50	5.78	2305	2.650	7.70	3080	2.78	9.87	3950	2.95	17.70	7075	3.52	25.50	8200	3.70
4 1/2"	2.57	1030	2.60	4.35	1740	2.75	6.35	2540	2.920	8.53	3420	3.08	10.94	4370	3.26	19.48	7790	3.87	22.60	9025	4.07
5"	2.84	1135	2.87	4.77	1910	3.02	6.95	2780	3.200	9.36	3750	3.38	11.97	4790	3.57	21.25	8500	4.23	24.62	9850	4.45
6"	3.35	1342	3.39	5.62	2250	3.56	8.20	3280	3.775	11.10	4450	4.01	14.21	5680	4.24	25.30	10110	5.02	29.30	11720	5.29
7"	3.83	1533	3.87	6.40	2570	4.06	9.40	3760	4.325	12.70	5080	4.58	16.18	6470	4.82	29.10	11640	5.78	33.70	13480	6.09
8"	4.27	1710	4.32	7.20	2880	4.55	11.00	4398	5.050	14.24	5700	5.14	18.25	7300	5.45	32.60	13030	6.45	37.65	15050	6.84
9"	4.75	1900	4.80	8.00	3200	5.05	11.62	4650	5.350	15.80	6330	5.71	20.35	8130	6.07	36.25	14500	7.21	42.10	16840	7.60
10"	5.26	2100	5.32	8.86	3550	5.61	12.68	5065	5.925	17.55	7030	6.34	22.05	8820	6.58	40.20	16100	8.01	46.70	18690	8.44
12"	6.18	2475	6.25	10.46	4190	6.62	15.00	6000	6.995	20.65	8270	7.46	26.44	10580	7.89	47.40	18950	9.42	55.40	22120	10.00
14"	6.74	2700	6.82	11.40	4570	7.22	16.60	6635	7.625	22.40	8980	8.10	28.90	11560	8.62	52.00	20800	10.34	60.50	24200	10.92
16"	7.66	3065	7.74	12.95	5190	8.20	18.82	7525	8.650	25.50	10200	9.20	32.80	13120	9.79	58.76	23500	11.70	68.40	27320	12.34
18"	8.58	3440	8.68	14.53	5820	9.20	21.00	8400	9.650	28.60	11450	10.33	36.10	14460	10.80	65.40	26150	13.00	76.50	30570	13.80

In these tables coal has been figured at $4.00 per ton of 2000 lb.—13,000 B.t.u. per lb. of coal—labor, boiler room expense, etc., taken at $1.00 per ton, making total value of coal fired at $5.00 per ton. Boiler efficiency taken at 70 per cent. Air temp. 70 deg. fahr. Experimental data obtained at the Mellon Institute.

per sq. ft. per hour. With steam at \$0.20, the value of the loss per year = $\frac{89.5 \times 8760 \times 0.20}{1{,}000{,}000}$ = \$0.157 per sq. ft. of covered surface.

Annual Fixed Charges

The annual fixed charges are determined from the first cost of the covering, the cost of the application of the covering, and the annual interest and depreciation charges.

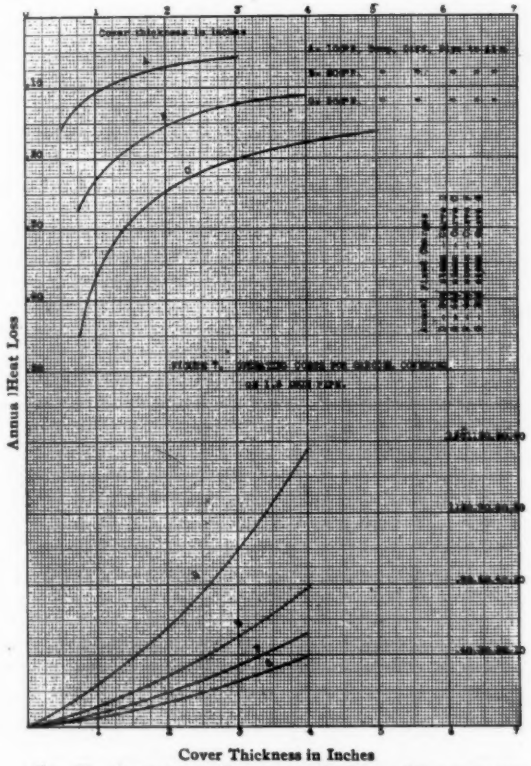


FIG. 7. OPERATING COSTS FOR CAROCEL COVERING ON 1.5-INCH PIPE

It is obvious that the first cost of the covering is not always the same for a given covering; also that the cost of the application of the covering will vary somewhat for different conditions, localities, etc. But in order to make any calculation for the economic thickness, it is necessary to assume some fixed cost of covering and a fixed cost of applying the covering. The influence of variations in the cost of the covering as well as in its application on the economic thickness curve will be discussed later.

In this paper the cost of the coverings has been taken as follows:

Air Cell, list minus 70 per cent;
Carocel, list minus 60 per cent;
85 per cent Magnesia, list minus, 55 per cent;
Multi-Ply, list minus 35 per cent.

The cost of the application of the covering has been assumed as practically the same for each type of material and has been taken as 20 per cent of the list price

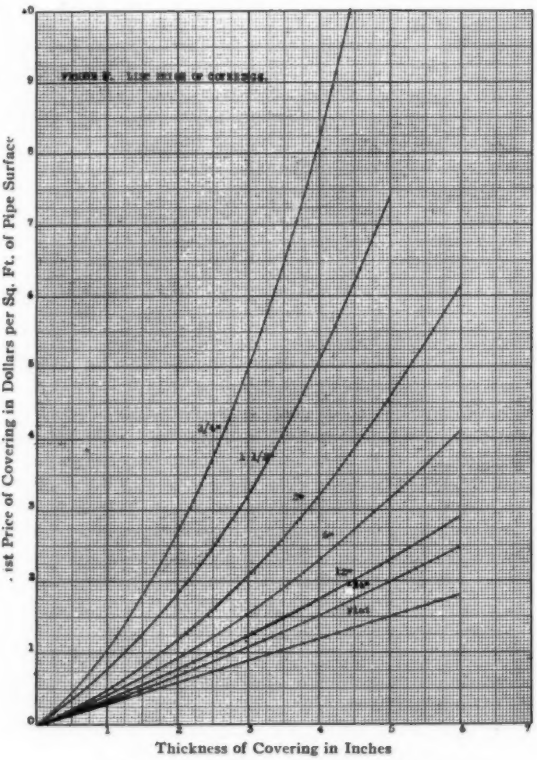


FIG. 8. LIST PRICE OF COVERINGS

of the covering. The annual fixed charges have been taken as 13 per cent of the total cost (interest, depreciation and miscellaneous). For example, the annual fixed charges on Carocel covering were as follows: List + 20 per cent cost of installation = 120 per cent — 60 per cent discount = 60 per cent of cost of covering installed. $0.60 \times 0.13 = 0.078 = 7.8$ per cent of list price as the annual fixed charges for Carocel covering.

The list price of 85 per cent Magnesia covering is shown in Table 3. This list is used in quoting prices on all types of covering on the market at present.

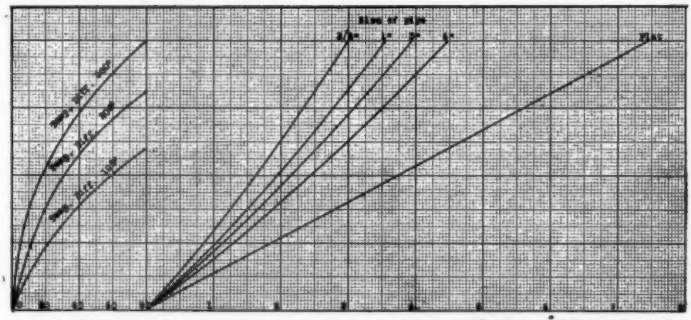


FIG. 9. ECONOMIC THICKNESS OF AIR-CELL

The actual cost of any given type of insulation is quoted at so many points of the list price.

The list price of pipe coverings given in Table 3 per foot length of covering has been calculated to list price per square foot of pipe surface for $^3/_4$ in., $1^1/_2$ in., 3 in., 6 in., 12 in., 24 in., and flat surface. These costs are shown in Fig. 8.

The annual fixed charges for the various coverings were determined from Fig. 8. To illustrate, the annual fixed charges on 2-in. thick Carocel covering on $1^1/_2$ in. pipe are = $0.078 \times 1.77 = \$0.138$ per sq. ft. The annual fixed charges for various thicknesses of Carocel covering on a 1.5 in. pipe are shown in Fig. 7 below the curves for the annual operating expenses of various thicknesses of Carocel covering on a 1.5-in. pipe.

Having plotted the annual operating expenses for various thicknesses of covering for temperature differences of 100, 200 and 300 deg. fahr., with steam at 20 cents per 1,000,000 B.t.u., and the annual fixed charges for various thicknesses of covering, on the same sheet of paper, there are several methods by which the economic thickness can be obtained.

One method of solution would be to measure and record the ordinate or value represented by the distance measured downward (along the 1-in. thickness line)

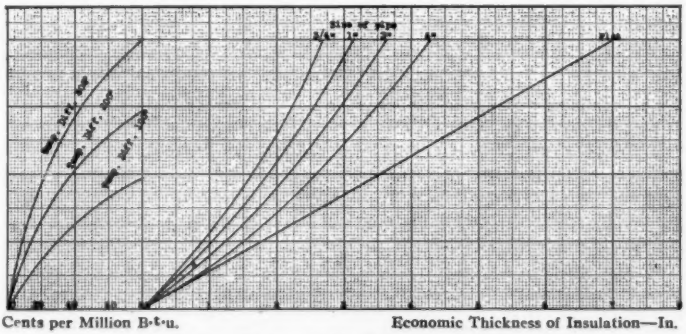


FIG. 10. ECONOMIC THICKNESS OF CAROCEL

from the upper axis to the *A* Curve, and also to measure and record the ordinate or value represented by the distance measured upward (along the 1-in. thickness line) from the lower axis to the *D* curve. The sum of these two values would represent the annual cost for 1-in. thickness. The same process would be repeated for other thicknesses, chosen preferably at 0.1-in. intervals. Then the thickness giving the smallest loss could be selected.

A quicker way would be to locate the thickness at which the tangent to the *A* curve and the tangent to the *D* curve were parallel. At that point the rate of change of each curve would be the same, and the total loss would be a minimum.

Moving to the right would increase the *D* curve more than it would decrease the *A* curve; moving to the left would increase the *A* curve more than it would decrease the *D* curve.

By this method of tangents, curves *A*, *B*, and *C* were employed with curve *D*,

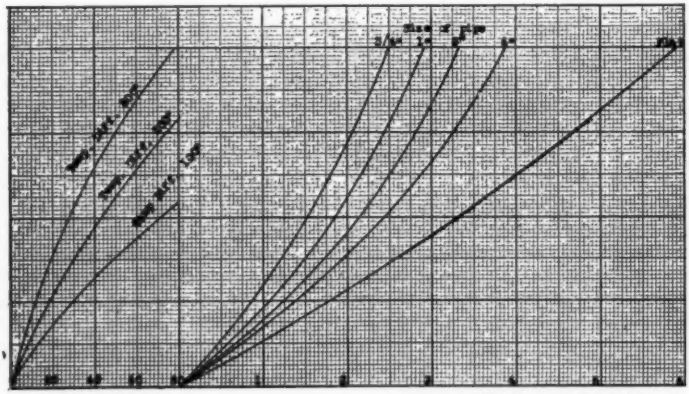


FIG. 11. ECONOMIC THICKNESS OF MAGNESIA

and the economic thickness for each temperature difference was determined for 3-in. pipe with steam at 20 cents per 1,000,000 B.t.u.

For steam at 40 cents per 1,000,000 B.t.u., it would be necessary to plot curves *A*, *B*, and *C* with ordinates twice as great, since the same B.t.u. loss would represent twice as great a cash loss. The annual fixed charges and, therefore, the *D* curve would remain unchanged. The method of tangents could be used as before, and the economic thickness could be determined. That plan, however, would involve replotting curves *A*, *B*, and *C*. A less laborious procedure would be to leave the curves *A*, *B*, and *C* unchanged but to double the values of the ordinates; that is, make each square measured downward count for twice as much cash value.

It would then be necessary to replot the *D* curve. The actual cash values of annual fixed charges would remain unchanged; but since the value of the ordinate scale was doubled, the *D* ordinates would have to be divided by two. Curve *E* would be the result. Thus curve *E* would be plotted on the same scale as curves *A*, *B*, and *C*, and could be used with them in the tangent method. The result would be the economic thickness with steam at 40 cents per 1,000,000 B.t.u.

For 60 cent steam, the ordinate of curves *A*, *B*, and *C* were made of triple value, and curve *D* was replotted as curve *F*. For 80 cent steam, the ordinates of curves *A*, *B*, and *C* were made of quadruple value, and curve *D* was replotted as curve *G* with ordinates one-fourth as great but of equal cash value with the *D* ordinates.

The results from the tangent method on this one curve sheet gave all the required economic thicknesses for 3-in. pipe. The same process was used for the other pipe sizes and for flat surfaces.

The resulting economic thickness curves for Air Cell, Carocel, 85 per cent Magnesia, and Multi-Ply coverings are shown in Figs. 9, 10, 11 and 12. From these four figures it is possible to determine the economic thickness of any covering now on the market. This determination can be made with sufficient accuracy for engineering purposes by selecting the figure for the covering whose thermal conduc-

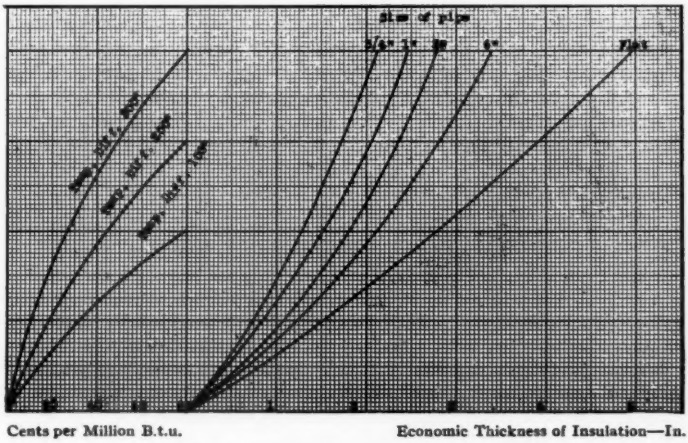


FIG. 12. ECONOMIC THICKNESS OF MULTI-PLY

tivity and cost are approximately the same as those of the covering whose economic thickness is to be determined.

It should be mentioned here that fairly wide variation in thickness of covering causes little difference in the total annual charges, so that the commercial thickness which most nearly fits the curves can be chosen with little sacrifice in economy. It should be kept in mind, however, that when in doubt a greater rather than a lesser thickness is usually chosen, as the covering generally pays for itself in a very short time.

The question will probably be asked as to how the economic thickness curves will be affected for coverings on a heating system which is in operation only a part of the year. Owing to the fact that the annual fixed charges will remain the same, while the annual operating expenses will be reduced proportionately to the reduction in time of operation, it will be found that the economic thickness can be determined by multiplying the B.t.u. actual cost, by the proportion of actual monthly operation to 12 using this as the B.t.u. cost instead of the actual cost. For example if the actual cost of the heat is $0.60 per 1,000,000 B.t.u. and the

system operates 6 months of the year, the cost to use in determining the economic thickness = $\$0.60 \times \frac{6}{12} = \$0.30$.

TABLE 3. PRICE LISTS—85% CARBONATE OF MAGNESIA PIPE COVERINGS

For Wrought Iron Pipes

Nominal Pipe Size Inches	Thickness of Standard Covering Inches	Price per Lineal Foot Canvas Jacketed	Thickness of Covering Inches	Price per Lineal Foot Canvas Jacketed	Thickness of Covering Inches	Price per Lineal Foot Canvas Jacketed	Double Layer Double Standard Thickness Inches	Price per Lineal Foot Canvas Jacketed	Double Layer Total Thickness Inches	Price per Lineal Foot Canvas Jacketed
1/2	1/2	$0.22	1 1/2	$0.46	2	$0.75	1 3/4	$0.65	3	$1.20
3/4	1/2	.24	1 1/2	.49	2	.80	1 3/4	.70	3	1.35
1	1/2	.27	1 1/2	.52	2	.85	1 3/4	.75	3	1.40
1 1/4	1/2	.30	1 1/2	.56	2	.90	1 3/4	.80	3	1.45
1 1/2	1/2	.33	1 1/2	.60	2	.95	1 3/4	.85	3	1.55
2	1 1/32	.36	1 1/2	.64	2	1.00	2 1/16	.90	3	1.65
2 1/2	1 1/32	.40	1 1/2	.70	2	1.05	2 1/16	1.00	3	1.75
3	1 1/32	.45	1 1/2	.76	2	1.15	2 1/16	1.10	3	1.90
3 1/2	1 1/32	.50	1 1/2	.82	2	1.25	2 1/16	1.20	3	2.05
4	1 1/8	.60	1 1/2	.88	2	1.35	2 1/4	1.40	3	2.20
4 1/2	1 1/8	.65	1 1/2	.94	2	1.45	2 1/4	1.50	3	2.35
5	1 1/8	.70	1 1/2	1.00	2	1.55	2 1/4	1.60	3	2.50
6	1 1/8	.80	1 1/2	1.10	2	1.70	2 1/4	1.80	3	2.70
7	1 1/4	1.00	1 1/2	1.20	2	1.85	2 1/2	2.25	3	2.90
8	1 1/4	1.10	1 1/2	1.35	2	2.00	2 1/2	2.50	3	3.15
9	1 1/4	1.20	1 1/2	1.50	2	2.20	2 1/2	2.70	3	3.40
10	1 1/4	1.30	1 1/2	1.65	2	2.40	2 1/2	2.90	3	3.65
*12	1 1/2	1.85	1 1/2	1.85	2	2.70	3	4.10	3	4.10
14	1 1/2	2.10	1 1/2	2.10	2	3.00	3	4.60	3	4.60
16	1 1/2	2.35	1 1/2	2.35	2	3.30	3	5.10	3	5.10
18	1 1/2	2.60	1 1/2	2.60	2	3.60	3	5.60	3	5.60
20	1 1/2	2.85	1 1/2	2.85	2	4.00	3	6.00	3	6.00
24	1 1/2	3.30	1 1/2	3.30	2	4.50	3	7.00	3	7.00
30	1 1/2	4.00	1 1/2	4.00	2	5.50	3	8.40	3	8.40

* All coverings larger than 10 inches furnished in segment form; jackets and bands not included.

Double standard thickness—the inner layer is furnished in sections for pipe sizes up to and including 10 inches, and in curved blocks for larger sizes. The outer layer is furnished in sections for pipe sizes up to and including 8 inches, and in curved blocks for larger sizes.

Double 1 1/2-inch thickness—the inner layer is furnished in sections for pipe sizes up to and including 10 inches, and in curved blocks for larger sizes. The outer layer is furnished in sections for pipe sizes up to and including 7 inches, and in curved blocks for larger sizes.

85% CARBONATE OF MAGNESIA BLOCKS

For Covering Boilers and Similar Surfaces

Thickness Inches	Price per Sq. Ft.	Thickness Inches	Price per Sq. Ft.	Thickness Inches	Price per Sq. Ft.	Thickness Inches	Price per Sq. Ft.
1/8	$0.30	1 1/2	$0.45	2 1/8	$0.64	2 3/4	$0.83
1	.30	1 5/8	.49	2 1/4	.68	2 7/8	.87
1 1/8	.34	1 3/4	.53	2 3/8	.72	3	.90
1 1/4	.38	1 7/8	.57	2 1/2	.75	3 1/4	.98
1 3/8	.42	2	.60	2 5/8	.79	3 1/2	1.05
STANDARD BLOCK SIZES, 6 × 36 in., 3 × 18 in.						4	1.20

In instances where the steam cost is not known, the cost per ton of coal can be calculated to cost per 1,000,000 B.t.u. by dividing the cost per ton by the B.t.u. value of the coal multiplied by the efficiency of the boiler. An efficiency of about 50 per cent can be assumed for domestic steam and hot water systems, and about 65 per cent for larger building units.

Since one ton of coal contains approximately 28,000,000 B.t.u., the cost of heat for a domestic boiler operating at 50 per cent efficiency and coal cost of $6.00 per ton = $\frac{\$6.00}{28 \times 0.50} = \$0.43$ per 1,000,000 B.t.u.

DISCUSSION

L. B. McMILLAN (WRITTEN): The discussion of insulation in connection with heating systems of residential buildings is most timely. It is true that in a great many cases, particularly in private residences, pipes and boilers are not insulated at all, and in a great many others, they are but poorly insulated.

Referring to pp. 37 and 38, January JOURNAL, the laminated insulations referred to are rarely required in residential buildings, yet since the author has introduced comparisons of materials by name, it is important that the record be set straight in two particulars: first, the description of Asbesto-Sponge Felted, and second, the relative conductivities of the two materials of the laminated type. The author's description of Asbesto-Sponge Felted as having spongy material placed between the layers is not correct. The sponge is incorporated into the felt of each layer. The distinction is that in addition to the advantages of the laminated structure, the insulating value of the felt itself is increased by this feature of the construction.

The conductivities shown in Fig. 1, agree closely for the most part with those in the author's paper in the *Journal A.S.M.E.*, Oct., 1924. At that time the average number of tests was shown to be approximately six for each material and only two for one of the materials as compared with approximately ten referred to in the present paper, yet most of the curves are identical. In the case of Multi-Ply, the author shows slightly higher conductivities at the lower temperatures than in his former paper, but his curve is still much lower than that obtained from tests made by the writer on the same material.

Results of the writer's tests on the two types of laminated insulation referred to are shown in Fig. A. For purposes of comparison, the author's results are also plotted on the same sheet. It will be noted that the two tests agree very closely on Asbesto-Sponge Felted, but that the conductivities of Multi-Ply found by the writer are about 20 per cent higher than those shown by the author. The writer's curve on Multi-Ply represents the lowest conductivities found on any of six tests of that material, and are representative of material purchased on the open market shortly before the author's conductivity values were published. Therefore, the material in question was not old samples as suggested by the author in his reply to the discussion of the *A.S.M.E.* paper referred to above. Tests on such older material showed even higher conductivities.

The author shows conductivities of Air-Cell slightly lower than those of Asbestocel, and yet Fig. B of this discussion plotted from Fig. 1 and Fig. 2 of the author's *A.S.M.E.* paper referred to, shows a considerably higher actual rate of heat loss through Air-Cell than through Asbestocel of the same nominal thicknesses. Materials of this type are made up with a given number of plies per inch of nominal thickness, and the true comparison of the insulating values of such materials must be made by comparing the heat losses through the materials as they are. To make this comparison between the author's tests on the two materials on the conductivity basis (per 1-in. thick) is to compare the insulating value of less than four plies of Asbestocel with that of more than four plies of Air-Cell. Furthermore, the author will doubtless agree that, since his tests were made on material of a given thickness per ply, the same conductivities would not apply to material of a different thickness per ply.

For example: four-ply material $^1/_8$-in. thick per ply should have a lower conductivity than four-ply material $^1/_4$-in. thick per ply, other things being equal, yet in spite of its lower conductivity the first material would show a *much greater heat*

loss than the second. This extreme case illustrates clearly how consideration of conductivity alone might be highly misleading. What interests the user of such materials is the magnitude of the losses through the materials as used, and the author's results show clearly that the materials as actually tested showed a rate of heat loss about 10 per cent lower for Asbestocel than for Air-Cell.

While it is true that the thicknesses of insulation used in connection with heating systems are often insufficient, the writer does not believe that it would be economical to use thicknesses as great as those shown by the author. For example, one would hardly consider applying 3-in. thick 85 per cent Magnesia Blocks on a heating

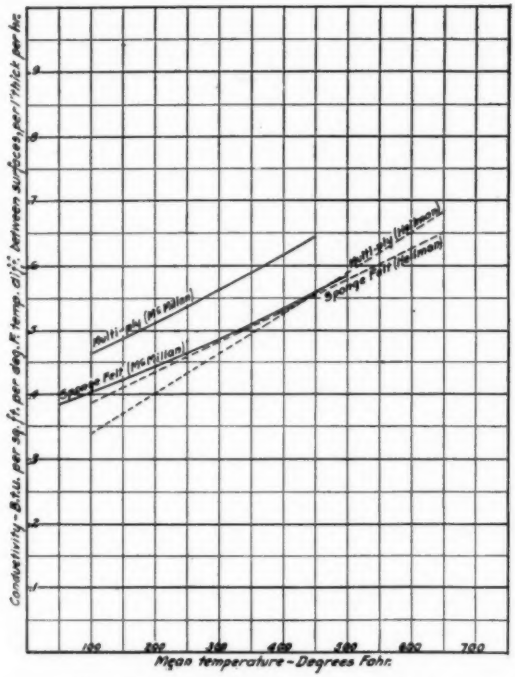


FIG. A. COMPARISON OF TEST RESULTS

boiler at 100 deg. temperature difference, yet this is the thickness which the author's chart shows would be economical for a cost of heat of 60 cents per million B.t.u., and a cost as high as this, or even considerably higher is not uncommon in residence heating. Neither would one be likely to apply 2-in. thick cellular covering on a 1-in. pipe under the same conditions.

In reference to operation of heating systems for only part of the year, the author says that for six months' operation the economic thickness will be somewhat less than for full time operation, but does not state whether the change should be much or little, nor does he explain how the period of operation may be taken into account.

As a matter of fact, the period of operation is just as important as the cost of heat in determining the economical thickness. Half time operation at a given cost of heat is practically equivalent, so far as heat losses are concerned, to full time operation at a cost of heat one half as great. In like manner, other periods of part time operation may be taken into account.

It is obvious, therefore, that the thicknesses shown by the curves are much greater than are justified, for heating system conditions. While the writer is very much interested in effective and economical insulation, he believes that progress toward this end can best be furthered by conservative recommendations.

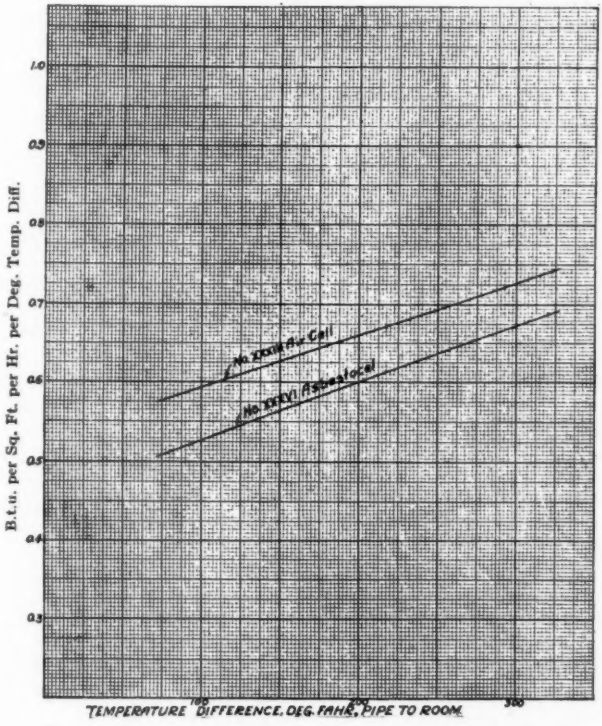


FIG. B. COMPARISON OF HEAT LOSSES FROM AIR-CELL AND ASBESTOCEL INSULATION

R. H. HEILMAN (WRITTEN): Replying to Mr. McMillan's discussion the curve for Multi-Ply covering given in this paper is the same as that given in the author's paper in the October, 1924 *Journal A.S.M.E.*

This curve is truly representative of Multi-Ply covering as it is made at present, as the tests on Multi-Ply covering were conducted in identically the same manner and on the same apparatus that the other coverings were tested on.

Any one familiar with pipe covering could not but be impressed that the curve

given by Mr. McMillan for Multi-Ply covering is considerably higher than would be expected from a material of this type. At 100 deg. mean temperature, Mr. McMillan's curve shows Multi-Ply covering to have practically the same conductivity as Carocel covering at the same temperature. Furthermore, Mr. McMillan states that his curve is the lowest of six curves. The author takes from this statement that Mr. McMillan wishes to imply that Multi-Ply covering is even inferior to Carocel covering.

Such a condition is obviously impossible and indicates that his tests were not representative of this material or were very much in error.

In regard to the curves for Air-Cell and Asbestocel, the author believes that the conductivity per 1-in. thick is the logical way in which conductivity curves should be presented and especially when the curves are the average results of tests on coverings of 1-in., $1^1/_2$-in. and 2-in. thickness.

While the overall loss curves shown by Mr. McMillan in Fig. B gives the heat loss through Air-Cell covering 0.94-in. thick and through Asbestocel covering 1.11-in. thick, the conductivity curves given by the author in Fig. 1 are the average curves from results obtained on tests of 1-in., $1^1/_2$-in. and 2-in. thick material.

The author agrees with Mr. McMillan when he states that one would not consider applying 3-in. thick 85 per cent Magnesia on a heating boiler operating at 100 deg. temperature difference with heat at 60 cents per million B.t.u. The economical thickness to apply, however, would be 3 in. as shown by the curves if the heating plant was in continuous operation 12 mo. of the year. However, a heating plant is generally operating not more than 6 mo. of the year and it would, therefore, not be economical to insulate with 3-in. thickness. The proper thickness to use in this case would be obtained by using a fuel cost of $60 \times 6/12$ or 30 cents per million B.t.u. and applying this cost to the curves, obtaining $1^3/_4$ in. as the correct thickness to apply.

In reference to operation of heating systems for only part of the year, the author explained fully when presenting the paper how the period of operation should be taken into account.

No. 741

HAS AIR A VITAL PROPERTY?

By F. E. HARTMAN,[1] SCOTTSDALE, PA.

MEMBER

THE recent work of the Research Laboratory, of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS is classic of its kind. The comfort zones, as determined by them, showing the relationship of temperature, humidity and air movement, represent one of the most comprehensive pieces of research known to the physical sciences.

It has removed, forever, from the realm of doubt, the necessity of the proper control of these factors, and stands an unimpeachable indictment of ventilating methods which do not admit of proper control.

This work has been published and presented in a very comprehensive form, yet today there are murmurings of rumors of a return to window ventilation with gravity exhaust. Rarely is a rumor given credence in high places unless it has some foundation in fact, and it is the probable grain of truth in this rumor to which attention is called.

Early theories of ventilation are familiar to all. It found its origin in the idea that CO_2 was actually toxic towards animal life. This theory gradually fell into disrepute, and was replaced by the so-called Organic Toxin Theory, which tended to account for the discomfort experienced in badly ventilated places, on the grounds that expired air actually contained a poisonous substance. The classical work of Haldane,[2] Billings,[3] Mitchell, Bergey and others, effectively and permanently exploded this theory; and the attention of investigators was directed towards the physical properties of air as a solution. Since the Research Laboratory of the Society has made such rich contributions to this phase of the ventilating art, suffice it to say that there are definite optima for temperature, humidity and air movement conditions, and that these factors are entirely too potent to be disregarded.

The personal experience of every engineer will tell him that to produce the optimum conditions of temperature, humidity, etc., a mechanical ventilating plan of the highest order is required. The writer has personally inspected many such plants, and the proper regulation of these factors, in ventilation, is today an accom-

[1] Chief Chemist, United States Ozone Co.

[2] Haldane, J. S., Respiration. Yale Univ. Press, 1922.

[3] Billings, J. S., Mitchell, S. W., and Bergey, D. H. Composition of expired air and its effect on animal life. Smithsonian Contributions to Knowledge—Vol. 29, Part I, 1903.

Paper presented at Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Buffalo, N. Y., January, 1926.

plished fact. However, is the engineer justified in stopping here? Even under the best conditions of artificial ventilation all are more or less agreed that there is something lacking that prevents comparison with outdoor conditions, always assuming, of course, that optimum temperature, etc., conditions exist on the outside.

The immediate effect of temperature, etc., on the system, is mainly nervous, and it is important both to health and comfort to protect the nerves against unfavorable stimuli. However, air has a very definite function in the human economy, and this really should be the starting part in an investigation.

Air is serviceable to man for the oxygen it contains. This oxygen is utilized in eliminating destroyed tissue from the body through the process of combustion, which is a chemical reaction. The oxygen of the air is also called upon to assimilate the products of putrefaction and decay, which is accomplished by oxidizing them, either back to their original elements, or rendering them otherwise useful, or innocuous to man. These demands on the air necessitate a high state of chemical activity of its oxygen, and chemically active air may well be called fresh air, for when it is chemically active it is capable of maintaining itself fresh.

It is now generally recognized that chemical activity is, in a sense, an electrical phenomenon, and in the reaction of gases, chemical activity requires that the reacting gas be electrically excited, or ionized. The oxygen of nature is generally maintained in a fairly high state of electrical excitement, due to the ionizing influence of the short wave length emanations of sunlight, radio-active changes in the earth's crust, lightning, etc. It is also generally understood that the life of an ion is very short, and that air must be continually under the influence of ionizing conditions in order to retain its activity.

It is further known that the handling of air in a mechanical ventilating system, its passage through stack heater, along grounded metal ducts, etc., is a very effective way of deionizing it. It is thus seen that the air handled by a mechanical ventilating system has lost much of its chemical activity. Here there is an actual difference between mechanically handled air, and the air of nature. It is not a difficult matter to demonstrate the relative difference in the extent of ionization of two atmospheres, and as surprising as it may seem, the ratio of ionization between fresh rural air, and air of a mechanically ventilated building, may be as high as 80 to 1. It seems, therefore, that there is a striking, and very important difference between the air of nature and the air of mechanically ventilated buildings. It behooves the Society to investigate further into this particular phase of air quality.

Ozone has been frequently discussed in the ranks of the Society. It has been exploited for ventilation for many years, many erroneous claims have been made for it, and undoubtedly this has obscured, to a great extent, its actual value to the art. As a germicide, the claims made for ozone cannot be sustained, since ozone cannot be employed in ventilation in the concentration necessary to germicidal action. However, from evidence extant, there is little need of a germicidal agent for general ventilation.

Ozone is, beyond doubt, an excellent deodorant. It readily attacks such products of putrefaction as trimethylamine, indole, skatole, etc., oxidizing them to odorless and innocuous products. Ozone further oxidizes hydrogen sulphide to free sulphur and water; this is an excellent quantitative reaction. The odors of tobacco smoke are readily eliminated by ozone, and the continuous addition of ozonized air to an atmosphere containing tobacco smoke, will cause a fairly rapid settling out of the smoke particles. Practically all of the odors of cooking, odoriferous gases given off by foods, and many of the industrial odors are destroyed,

and not masked by ozone. For use in general ventilation, ozone is the deodorant par excellence.

These properties of ozone alone are sufficient to establish its place in ventilation; however, they are merely the obvious advantages of its use. There are other, more subtle advantages, which vastly outweigh, in importance, those just enumerated. These subtle advantages lie in the restoration to the air of buildings, its normal chemical activity.

Chemical activity is on the whole electrical in character, and most pronouncedly so in the reaction of gases. Without attempting to go into the exact mechanism of chemical activity it may be briefly said that substances react with each other in the attempt to reach a state of great stability. Stability seems to be the divine purpose. If this is true it naturally follows that the less stable a substance, the greater will be its activity towards stability. If the ideal oxygen molecule is considered, two atoms of oxygen are perceived, consisting of a number of exceedingly small entities called electrons, differing in polarity, but each balancing the other so as to give perfect atomic equilibrium; and the two atoms, in turn, balancing each other so as to give perfect molecular equilibrium. Here there is a system of great stability, ill inclined towards activity. It has been remarked that chemical activity is due to ionizing effects of certain natural phenomena. These small entities of the atom, which are called electrons, differ in electrical polarity, are not rigidly welded to the atomic system; and by virtue of their presence in equal amounts, produce atomic stability. If there are added to such a system, or taken away from it, certain electrons of one polarity only, equilibrium or stability will be destroyed and thus the system induced to activity in an effort to again attain stability. The effect of short wave-length emanations of the sun is to drive electrons from the system, split molecules and generally disrupt molecular and atomic stability. In radio-active changes, lightning, etc., there are other electrons hurtling through the air with an enormous energy, and these electrons collide with the atomic electrons of oxygen, dislodge them from the hitherto stable system and thus produce what are known as excited or ionized molecules. When oxygen is thus acted upon some of the molecules, by losing a negative electron, become electrically positive, and a neutral molecule may receive a negative electron that has been driven from another molecule, and become negative. Thus also positive and negative atoms may be formed. Some of these positive and negative atoms of oxygen will unite to form a tri-atomic molecule of oxygen called ozone. Normally oxygen is not stable with three atoms crowded into its molecule. It has a valence of two, and groups above this number tend to break down, or are very eager for reactions that will produce stability. This is the way that ozone is formed in nature, and ozone is a natural constituent of naturally pure air.

It is now also known that the passage of an electric current through a wire is nothing more than the passage of a stream of electrons. If an apparatus is arranged so that the metallic circuit is interrupted by an air gap, and the electrons made to traverse this air gap in their passage, and if a stream of air is then caused to pass through this air gap there will be a continuous passage of electrons through a stream of continuously moving air. The electrons emanating from the electric circuit will bombard the atomic electrons of the oxygen, and if conditions are right, a very large number of the oxygen molecules will be ionized and some ozone will be formed. If the bombarding electrons possessed sufficient energy, they would also activate nitrogen. But as oxygen is a better electron trap than nitrogen the bombarding electrons will activate more oxygen than nitrogen, and if care is taken to give to the bombarding electrons just the right amount of energy the

activation of nitrogen is practically obviated. That is what is done in producing ozone.

It should be noted that in subjecting air to electric discharges, the extent of the ionization of the oxygen is always enormously in excess of the amount of ozone formed; however, the amount of ozone formed is generally in proportion to the extent of ionization, thus, ozone can be used as a convenient index of the ionization.

Of the oxyaen passed through an ozonizer, only a very small fraction is converted into ozone, but a large portion is ionized, or chemically excited. In organic reactions, particularly, ozone is markedly catalytic in its action; that is to say, it promotes chemical action, or oxidation, in excess of the amount that can be quantitatively accounted for by the ozone present. The literature of ozone, particularly that which pertains to its chemical uses, is replete with instances of this so-called catalytic action; hence, it is seen that when ozone is employed it is not the oxidizing capacity of the ozone alone which is available but also a considerable quantity of chemically excited oxygen which accounts for its apparent catalysis. The writer is convinced that the value of this chemically excited oxygen is equal to that of the ozone, and has been hitherto almost entirely overlooked.

While therapeutics is scarcely within the scope of ventilation, in passing, however, it is interesting to note that ozone has been used to a sufficient extent, and by authorities of such standing, to demonstrate adequately its value in the treatment of respiratory diseases and anemia.

Dr. Augustus Caille[4] reports, in the Archives of Pediatrics, a total of twenty-two cases of ozone treatments, embracing six cases of chlorosis, mostly in youths, seven cases of pertussis, or whooping cough, in children from eighteen months to seven years of age. One case of bacillary phthisis, and one case of pulmonary hemorrhages, four cases of extreme anemia including one case from chronic lead poisoning, one case of extreme anemia since birth, one case of anemia complicated with chronic naso-pharyngeal catarrh, and one case of anemia in tuberculosis of the skin. He also reports a case of chronic bronchitis with great anemia, together with a case of tuberculosis of the apex of the left lung. Dr. Caille's paper contains a very complete record of each of these cases, and sums up his conclusions briefly as follows:

"Conclusions: Inhalations of ozone have not been followed by noticeable ill effects. Daily inhalations of ozone increase the quantity of oxyhemoglobin in the blood from 1 to 4% in a short time and this increase remains stationary for some time. In pertussis ozone inhalations have a very distinct curative effect as regards the duration and severity of the disease. In chlorosis and anemia ozone inhalations are exceedingly valuable from a therapeutic standpoint and give better and prompter results than any other form of medication. Atmospheric medication is readily secured, making this probably a valuable procedure in the treatment of diptheria, scarlet fever and other infectious diseases.

"I am convinced that it would be of value in pernicious anemia. The anemia children who came under treatment were very sick, especially the one case I referred to, in which everything had been tried, and it was really remarkable how soon this child picked up and became better in every way after inhaling ozone. I was thoroughly surprised at the results."

Dr. W. J. Morton[5] has obtained excellent results with ozone in the treatment of nasal catarrh, and in conclusion remarks as follows:

"If we turn to the prophylactic and hygienic properties of ozone, we must be struck with admiration.

[4] Caille, Augustus, M.D., Prof. of Children's Diseases, Post Graduate Medical School, New York Archives of Pediatrics, Vol. IX, Page 570.

[5] Morton, W. J., M.D., Prof. of Electro-Therapeutics. Post Graduate Medical School, New York, New York Medical Journal.

"Ozone attacks and renders innocuous organic matters such as smoke, sulphur compounds and the great variety of organic matters which contaminate the air we breathe. When experimentation and observation more accurate and of wider scope than any now at command, shall be available, I have no doubt that ozone will assume an important relation to the health of the individual and the community."

Dr. T. Caryle Beatty[6] writing in the British Medical Journal remarks as follows:

"The method of treating various disorders by inhalation of ozone has been found especially valuable in the treatment of anemia, and during the last two years I have treated a series of cases by this method with uninterrupted success."

M. Herard,[7] in a Bulletin of the Academy of Medicine (Paris) remarks:

"It has been fully demonstrated by many observations collected both in France and abroad, that the most serious and inveterate cases of anemia are cured by the inhalation of ozone."

Dr. J. T. Gibson in his book "Advanced Therapeutics" says of Ozone:

"In advanced cases of tuberculosis with cavities and much expectoration, I think there is no means of so much use as inhalation of ozone. It empties the lungs of the detritus and pus, revivifying the blood, disinfecting the parts of the lungs reached, and after the first irritation of its use has passed off, there is nothing that gives the lungs the sense of rest and quiet as does this agent. I have seen the quantity of sputum lessen to a most remarkable degree, fever disappear and all symptoms improve by the use of ozone inhalation."

Dr. Geo. Stoker, of the Oxygen Hospital of London, reports the value of ozone in the treatment of tuberculosis:

"Consumption has been subjected for the first time in this institution to atmospheric treatment. Cubicles have been erected in which patients can breathe continually treated air (ozonized) possessing most of the properties which characterize the air of climates known to be favorable to the relief or cure of this disease. The results have been remarkable. In all, nine cases have been thus treated during the past year; of these eight were discharged with the disease definitely arrested. The importance of this new departure cannot be exaggerated."

In the lungs, the blood comes into contact with the air which is breathed in. The venous blood gives up its products of oxidation (CO_2 and other gases), and the oxygen of the air combines with the free hemoglobin to form oxyhemoglobin. It has been seen that in cases of anemia, ozone has been successful in increasing the oxyhemoglobin as much as 4 per cent. Human beings depend upon oxyhemoglobin to free the system of dead tissue and toxic matter; generally, we are about as healthy as the blood. In the lungs there are equilibrium conditions between gases in solution and partial pressure of gases above the solution. When the effect of ozone in anemia is considered, it is conceivable that the extraordinary chemical activity of ozonized, or ionized air, produces an actual oxidation of some of the waste gases in the lungs, thus reducing their partial pressure, and producing a greater liberation of these gases from the blood. There is further an actual, chemical affinity between oxygen and hemoglobin, and it is further conceivable that the high activity of ionized air brings about a greater formation of oxyhemoglobin.

Much that has been written here, is in the realm of speculation, it remains to be proven; but it is sufficiently reasonable to justify a vigorous investigation. The thought to be stimulated is that there is some vital substance in the air of nature. It is known that natural air is one of the greatest stimulants and remedial agents known. It is to be regretted that it cannot be had in the heart of metropolises, where men are called upon to exert great physical and mental effort; however, air conditions have been produced in mechanically ventilated buildings, by the aid of

[6] Beatty, T. Carlyle, M.D. British Medical Journal.
[7] Herard, M., Bulletin de L'Acadamie de Medicine (Paris).

ozone, that possesses all of the zest, comfort and stimulation, characteristic of the purest air of nature. Ionization then is offered as the "air soluble vitamin," and herein perhaps lies the grain of truth to the exponents of window ventilation, for they have recognized the vital quality of outside air, but in their attempt to obtain it, they overlook a host of other factors, which cannot be successfully neglected. It is the duty of the engineering profession to protect humanity against half truths.

DISCUSSION

E. S. HALLETT: It is a great pity that a paper like that cannot be received by the public universally and the benefits of health to the children especially in schoolrooms be realized. You may not appreciate the merits of this paper as I do for I am probably the greatest user of ozone in the world. In St. Louis we have 80,000 children enjoying the benefits of ozone as outlined here. If we had waited until such information as we get here and such as I have presented on a number of occasions could be generally accepted and we could get approval from medical associations and people like that, we would still be marking time. We didn't have to wait as conditions there are admirable and we have on our board more than 12 regular practicing physicians who spend all their time in our schools. We have 25 or 30 nurses and between the physicians and the nurses all of the schools are under medical supervision every day.

We have been using ozone for about 8 years and every year are extending its use. In the beginning Dr. James Stewart, who now heads the State Health Board, promoted to that position from our city, inaugurated this work. Now we have Dr. Humphrey, who is making some special investigations, taking the non-ozonized school with the nearest ventilated ozonized school and he is conducting careful health comparisons between these schools. He is having all cases of illness and absence from the school analyzed and tabulated in such a way that when I return next year I will be able to present all of this data in an unquestionable form.

I was very much surprised yesterday to hear the Doctor speak about the terrible condition in the St. Louis schools. If that condition existed at all, our 12 physicians would certainly have heard of it and if they had heard of it, we certainly would have known of it. I want to tell you right here that it would be impossible for me to move 1 in. of anything in the administration that pertained to the health of the children in the St. Louis schools without their approval. We never experimented with the children of St. Louis. They are not our children. They are under our supervision and the supervision of the School Board and there is no officer of the Board who would have the right to indulge in any kind of experiment that had to do with the health of the children, either for good or bad. So that what we have done in this direction are not experiments. We experimented outside.

To give you a little slant on what happens sometimes, the Chief Clerk of our office had a bad case of influenza at one time and I took an ozone machine to his room and he got well. This same Chief Clerk had a very fine family physician. He had him at the house two or three times a month and made the habit of paying his doctor at the end of the year. One time the doctor sent his bill in the middle of the year so when he met the doctor the next time he said, "What do you mean by sending that bill now?"

"I see you have changed doctors; so I supposed you wanted a bill."

"I haven't changed doctors."

"I haven't been to your house in six months."

"Since we got to using an ozone machine in the house we haven't had an occasion to have a doctor."

XUM

No. 742

TEMPERATURE CONDITIONS EXISTING IN THE ROOMS OF A RESIDENCE HEATED BY A GRAVITY WARM AIR SYSTEM

By V. S. DAY, URBANA, ILL.

MEMBER

Object

THE program of tests for the Research Residence of the *National Warm Air Heating and Ventilating Association*, at the University of Illinois, includes an elaborate study of temperature conditions existing in the various rooms of the Residence as well as within the individual rooms. Observations of temperatures have been taken for one heating season and the data form the basis of this paper. The data and conclusions here presented will, together with much additional data along these same lines, be presented in a future bulletin of the Engineering Experiment Station of the University of Illinois.

Description

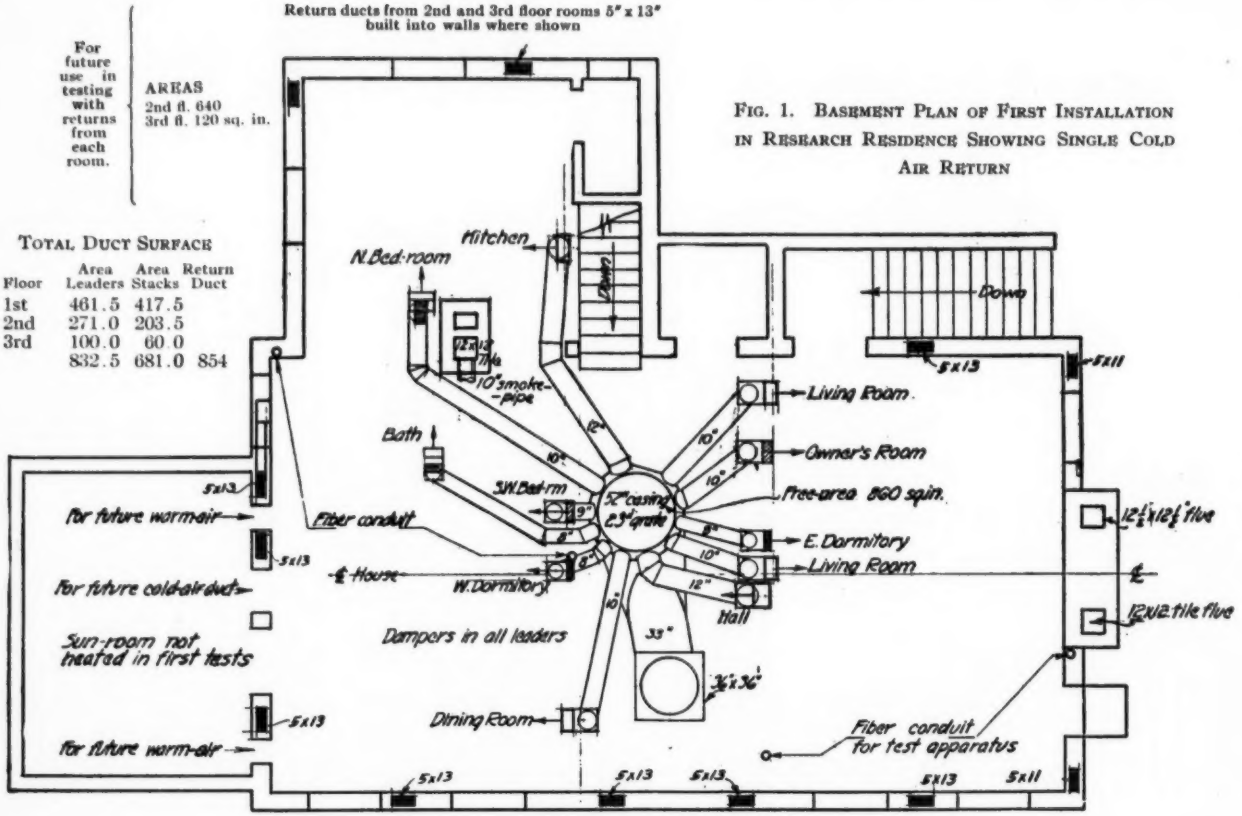
The warm air furnace installation in use during these temperature observations has been described in previous papers, but is shown again in Fig. 1. As the temperature data undoubtedly will be affected by the arrangement of warm air pipes and return ducts it is very important that any conclusions drawn take into account the general arrangement of the heating system.

Fig. 1 shows that only one cold air grille and return duct was used in the tests under consideration. This grille was located in the central hall of the Residence and air from the most remote corners of the house could only return by travelling across floors or down staircases to it. The pipe sizes were calculated according to the *Standard Code Regulating the Installation of Warm Air Heating Systems in Residences.*

In a central position in each of the ten heated rooms there was located a standard supporting three thermometers: one at the breathing level, another four inches above the floor and a third one, four inches below the ceiling. Throughout the tests a thermostat set at 70 deg. fahr. and located in a central point on the first floor, controlled the draft door movements. At the same time a recording thermometer graphed the outdoor and the indoor temperatures. The difference between the inside and outside temperatures recorded form the basis for the data plotted in Figs. 2, 3, 4 and 5.

Paper presented at Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Buffalo, N. Y., January, 1926.

XUM



BASEMENT PLAN

FIG. 1. BASEMENT PLAN OF FIRST INSTALLATION IN RESEARCH RESIDENCE SHOWING SINGLE COLD AIR RETURN

Results

In Table 1 temperatures for the entire house are tabulated and averaged. These tabulated data cover a period of 28 days during which a variety of weather conditions existed. For the period the dry bulb temperature outdoors averaged 36.6

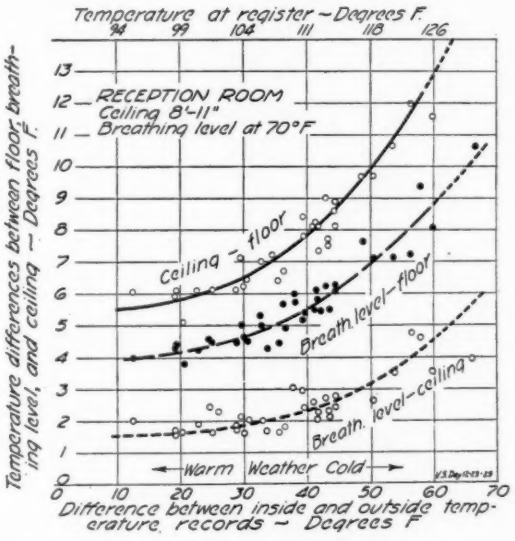


FIG. 2. TEMPERATURE DIFFERENCES BETWEEN VARIOUS LEVELS IN A FIRST FLOOR ROOM IN THE RESEARCH RESIDENCE

TABLE 1. RESEARCH RESIDENCE—ANALYSIS OF TEMPERATURES IN ROOMS FOR 28 DAYS, FROM OBSERVATIONS NOS. 15–42, INC.

Temperature deg. fahr. at	First Floor		Second Floor						Third Floor			
	Rec.	Din.	Kit.	Hall	Com.	S. W. Bed	Off.	Bath	W. Dor.	E. Dor.	Aver.	Out
Floor	64.4	62.3	63.4	69.4	66.1	64.1*	64.1	66.1	63.4	62.6*	64.6	
Breath. level	69.9	70.0+	69.2	71.2	70.7	68.1	67.2	69.7	67.0	66.1	68.9	36.6
Ceiling	72.1	71.3	70.8	73.0	73.5	70.2	68.6	71.0	69.2	69.5	70.9	
Aver. of floor breath. and ceiling	68.8	67.9	67.8	71.2	70.1	67.5	66.6	68.9	66.5	66.1	68.13	36.6
Average for each floor												
Floor			64.9			65.1			63.0			
Breath. level			70.1			68.9			66.5			36.6
Ceiling			71.8			70.8			69.3			
			68.9			68.3			66.3			
Ceiling heights			8'–11"			8'–4"			7'–0"			

* Windows open at night.
\+ Thermostatic control at this point.

deg. fahr. and the average of the thirty thermometers in the ten heated rooms of the Residence was 68.13 deg. fahr. At the breathing level the average of the ten dry bulb temperatures was 68.9 deg. fahr. From this average value of 68.9 deg. fahr. the coldest room varied only 2.8 deg. low and the warmest room 2.3 deg. high.

No effort was made to adjust the room temperatures by manipulation of pipe or register valves. All pipes were full open. Later such adjustment was tried and it was found that by partly closing four of the eleven valves the total range of temperature variations as read on the breathing level thermometers was 2.2 deg., or about 1.1 deg. from the mean.

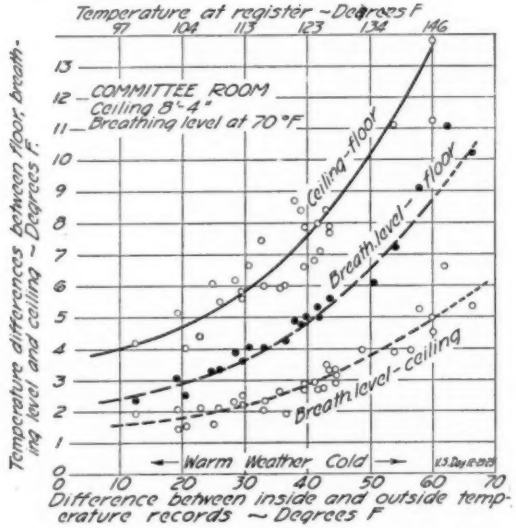


FIG. 3. TEMPERATURE DIFFERENCES BETWEEN VARIOUS LEVELS IN A SECOND FLOOR ROOM IN THE RESEARCH RESIDENCE

Between different levels in the rooms marked variations in temperature existed. Figs. 2, 3 and 4 show graphically the effects obtained, in rooms on first, second and third floors, with the indoor-outdoor temperature difference as the basis. The relatively narrow paths in which the experimental points arrange themselves indicate that the temperature differences may be correctly expressed as functions of the indoor-outdoor temperature difference.

The curves turn up rather sharply in the cold weather region, a condition which may be explained readily. Two factors operate to cause the condition, namely; relatively high temperatures of the air which leaves the registers and ascends to the ceiling, and relatively cold temperatures of the air which by infiltration and cooling at the wall surfaces descends to the floor.

The approximate air temperatures at the registers are shown at the tops of Figs. 2, 3 and 4.

In order to further visualize the data contained in Fig. 2 another form of charting

has been used in Fig. 5. Here the three thermometers are shown with the breathing level thermometer always maintained at 70 deg. fahr. The ceiling and floor temperature may be read directly from the chart for any outdoor temperature. Thus it is shown that in 20 deg. weather the floor temperature, in this particular room and installation, was 63 deg. fahr. and the ceiling temperature 73 deg. fahr. In zero weather the temperature variation between ceiling and floor might be as great as 17 or 18 deg.,[1] with the floor 12 deg. colder than the breathing level. Fig. 4 indicates that the temperature differential used in the calculation of the heat loss from the exposed ceilings of the third floor should have been 76 deg. instead of 70 deg.

It will be of interest to heating engineers to express the data in terms of temperature differences per foot of height. This has been done in Table 2 and it is shown

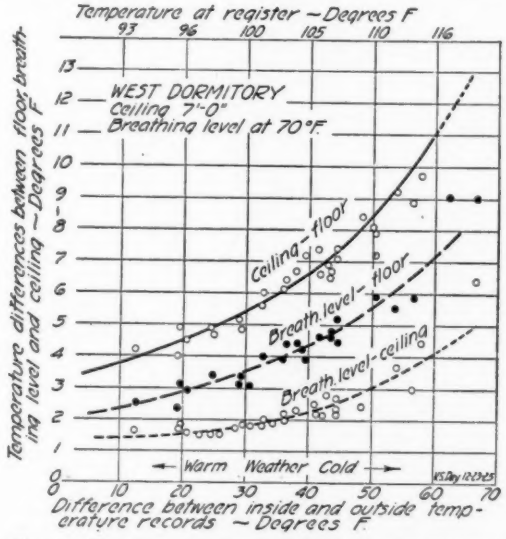


FIG. 4. TEMPERATURE DIFFERENCES BETWEEN VARIOUS LEVELS IN A THIRD FLOOR ROOM IN THE RESEARCH RESIDENCE

TABLE 2. TEMPERATURE INCREASE PER FOOT OF ELEVATION[2]

Outdoor temp. deg. fahr. 70 deg. fahr. inside at breathing line	Temperature Increase per Ft. of Elevation 1st floor	2nd floor	3rd floor
0	1.70	1.65	1.45
10	1.44	1.42	1.25
20	1.18	1.22	1.04
30	0.94	0.99	0.86
40	0.72	0.82	0.67
50	0.49	0.62	0.50
60	0.32	0.50	0.35
70	..	..	..

[1] No continuous zero weather existed and the tests are being continued for the verification of the accuracy of the curves.

[2] Table based on revised plotting of curves, Figs. 2, 3 and 4.

that the coefficient of temperature increase per foot of height was approximately 2.5 deg. zero weather, and 1.00 deg. in freezing weather.

In this connection, it is interesting to note that Rietshel's equation for the variation in air temperature above or below a breathing line temperature of 70 deg.

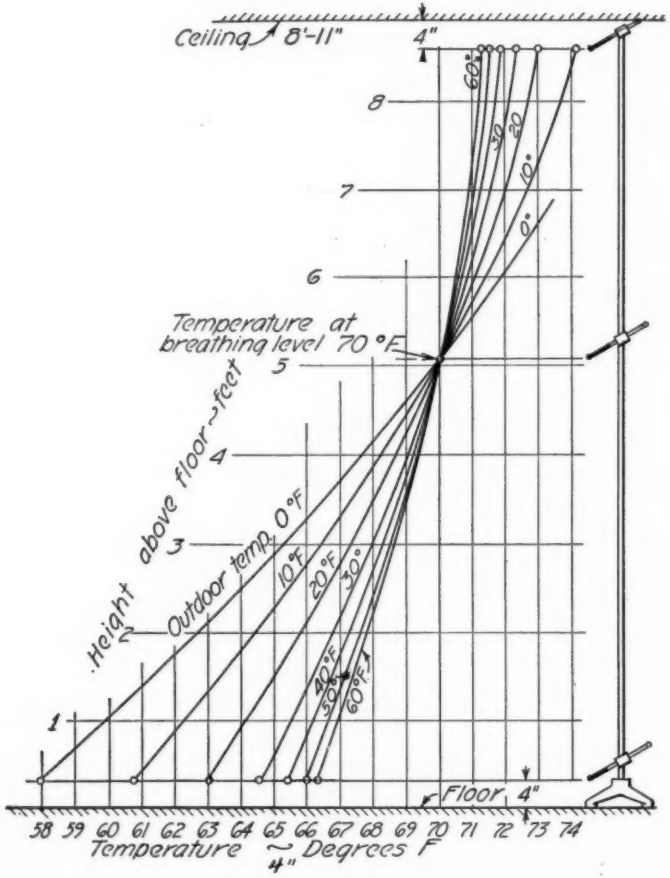


FIG. 5. RESEARCH RESIDENCE, RECEPTION ROOM, TEMPERATURE VARIATION WITH HEIGHT

fahr. in a room 10 ft. high and with an outside temperature of 0 deg. fahr., gives a correction of about 2 deg. fahr. per foot of height. Practice varies from this figure down to 1 deg. fahr. per foot for very high rooms, and a common allowance is 2 per cent of the breathing line temperature per foot of height above or below the breathing line. The effect of metal weather strips at all windows and separate

air return systems from each room on the variation in air temperatures between floor and ceiling will be determined in later tests in the residence.

The importance of such data as these in computing heat losses through cold floors and ceilings can hardly be overestimated and similar records on other types of buildings are greatly needed.

DISCUSSION

A. S. ARMAGNAC: What kind of coal was used and how frequently was the furnace fired?

A. C. WILLARD: This past winter the house was operated with anthracite coal of about 11,900 B.t.u. You will find the answer in the Experiment Station *Bulletin* No. 141. The coal was fired as required. For instance, three firings a day were usually all that were necessary except in the most severe weather. Whenever we felt there was not sufficient coal in the fire pot, refiring was resorted to. Normally three coalings a day are ample but some days only two were required. The idea was to keep the fire pot filled with fuel to the level of the bottom of the fire door in practically all cases.

F. D. MENSING: What kind of a thermostat was used?

A. C. WILLARD: An *on* and *off* type Minneapolis thermostat, I believe, was used. Now we have applied a dual thermostat which is so set that in addition to the control in the dining room there is a thermostat in the bonnet of the furnace so set that the temperature in the bonnet of the furnace cannot rise to an unusually high degree and cause the dining room thermostat to overrun.

F. D. MENSING: Is there any possibility of your trying the graduated type? I have had an interesting experience with a hot-water job using the last type of thermostat you mentioned. The action was this: The fire came up; the water rose to a high temperature so that the second story had a temperature of 80 deg. while the first floor had a temperature of 40 deg. We had to cut the *on* and *off* type out together with a regulator on the boiler. I think you will get some very interesting results if you try the graduated type.

J. A. DONNELLY: Prof. Willard mentioned limiting the maximum temperature of the smoke hood. Does he also change the minimum rate of burning in order to smooth out the flue temperatures?

A. C. WILLARD: It doesn't necessarily do that. The thermostat merely operates this dual control. This dual point is subjected to a high temperature and does nothing when subjected to a low temperature, because the house thermostat takes care of the closing of the draft damper.

J. A. DONNELLY: You are not only manually changing the temperature of the thermostat but also manually changing the minimum rate.

A. C. WILLARD: No, the manual change on this dual point control is so infrequent that we can almost forget it. Sometimes the outside temperature gets down to as low as 10 above. It simply means this: In case the draft has been increased and the furnace is trying to pick up the heat load of the house, it takes us a little longer to do it and we don't do it with such a rush.

QUESTION: I would like to ask Prof. Willard if he made any tests by circulating the forced circulation around the surface with the idea of getting the floor temperature near the ceiling temperature.

A. C. WILLARD: Not in the house but we have done that in the laboratory.

QUESTION: I conducted tests in a small way. I put a thermometer 6 in. from the ceiling and 6 in. from the floor and had a temperature difference of 13 deg. and I ran a fan half an hour and took readings and there was a difference of only 7 deg.

A. C. WILLARD: You dropped the temperature of your incoming air and at the same time you circulated more air and of course that must tend to equalize the floor and ceiling temperatures. In that connection I can say that in the front hall of this house where the circulating duct is located there is a difference between the floor and the ceiling sometimes of only 1 or 2 deg.

H. S. WHELLER: What arrangements were made to get the air back from the individual rooms?

A. C. WILLARD: The house is operated with the doors open; maybe not wide open but always open 6 in. We take pains to see that this condition is maintained although we have a few cases of closed doors. Frankly, there has been very little difference in the operation except in cold weather. In mild weather the house works all right with the doors closed.

E. C. EVANS: Have you done anything on humidity?

A. C. WILLARD: We have so far operated the plant with the manufacturer's water pan dry. During the latter part of last winter we used the manufacturer's water pan which is of cast iron construction placed between the ash pit and the fire doors. We kept it filled three times a day and the amount of evaporation was noted. The increase in humidity in the house was appreciable. That has been charted and will be reported. This winter we are operating the house with a pan placed in the bonnet of the furnace directly on top of the main casting where it receives heat by contact. We are running our humidities up to about 40 per cent. We are controlling them because we would have the house running with water if we didn't. That will all be reported on in the final report.

No. 743

OBJECTIVES AND STANDARDS OF VENTILATION

By C.-E. A. WINSLOW,[1] NEW HAVEN, CONN.

NON-MEMBER

IT IS a great pleasure to attend this annual meeting and to discuss with you the fundamental physiological standards which underly the work of the ventilating engineer. Physiologists, physicians and engineers alike are all engaged in one common task, the promotion of the health and well-being of mankind; and success can only be attained by the closest and most cordial mutual understanding as to the objectives which must be kept in view. The physiologists and the physicians are students of the human body, its reactions and its needs. It is for them to determine the conditions of the atmosphere which are most desirable for human health and comfort. The engineer is a master of the physical universe and it is for him to devise and maintain the mechanical apparatus capable of producing the conditions which the biologist finds to be most salutary.

The progress of the art of the ventilating engineer since John Shaw Billings first published his classic work on ventilation in 1884 has been a phenomenal one. With ever increasing assurance of success the engineer has designed fans and heaters and humidifiers and ducts and automatic regulating apparatus capable of maintaining those atmospheric conditions which were deemed to be desirable. This task has been accomplished without difficulty; but meanwhile conceptions of the nature of this task have changed and the time has now come for a radical revision of ventilation practice in the light of accumulated modern knowledge.

The science of ventilation, as it has been understood by the engineering profession from the time of Billings and Woodbridge almost to the present day, has been based on the conceptions of the German hygienist, von Pettenkofer, who in 1862 first clearly enunciated the view that the evil effects of the air of a badly ventilated room were due to alleged organic poisons excreted into the atmosphere from the human body, and that the object of ventilation was the removal of these poisons by dilution with fresh air. Even 60 years ago it was recognized by this pioneer in the science of hygiene that changes in oxygen and carbon dioxide con-

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tent, such as occur in the worst ventilated room under ordinary conditions, had no physiological significance. Only when oxygen content falls to 16–18 per cent and carbon dioxide content rises to 1–2 per cent are harmful effects produced; and these limits are never reached in any ordinary occupied room on the earth's surface. The conception that organic poisons cause the harmful effects of bad ventilation seemed, on the other hand, in the light of the knowledge of 50 years ago an entirely reasonable one and was naturally and inevitably accepted by the medical and the engineering world alike. To Pettenkofer, carbonic acid was of significance as an indirect measure of the presence of morbific matter and it is to him that we owe the assumption that air containing less than a certain amount of carbon dioxide is therefore good, and that air containing more than a specified amount is therefore bad. From this basic assumption it was easy to pass to a computation of per capita air supply and the standard of 30 cu. ft. per person per minute, or 2000 cu. ft. per person per hour is, as can be easily seen, a simple arithmetical statement of the amount of fresh air containing 3 parts of carbon dioxide per 10,000 which it is necessary to introduce, in order to prevent the concentration of carbon dioxide in an occupied space from rising above 6 parts per 10,000.

When the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS was organized in 1895 this concept of ventilation was universally accepted and it was natural and proper that the Society should lend its influence to the embodiment of the air dilution standard in the form of concrete legislation throughout the states of the Union. The movement has met with remarkable success, so that on the first of January, 1925, there were 24 states with laws or regulations specifying more or less definite standards for school ventilation based on the Pettenkofer theory. In 9 states, the standard was written into the statute law, in 7 it was a regulation of the state educational authorities, in 5 of the state health department and in 3 of other official bodies. It is true that these laws or regulations often apply only to certain classes of communities or types of buildings, yet as Prof. J. R. McLure has shown, in his valuable monograph on the ventilation of school buildings,[2] the general result has been to impose positive fan ventilation capable of furnishing an air supply of 30 cu. ft. per minute upon a very large proportion of the schools of the United States. Out of the 700 school buildings constructed between 1918 and 1925 in the large cities of the country, 73 per cent were equipped with systems of this type.

Science, however, is a progressive, not a static, thing, and while the Pettenkofer theory was in the process of crystallization in the form of restrictive legislation the whole basis on which it was founded had been undermined by the researches of more modern physiologists. There are five different changes in the atmosphere produced alike by human occupancy and by processes of combustion, a decrease in oxygen and an increase in carbon dioxide, in partially oxidized organic compounds, in temperature and in humidity. The first two of these changes were known to be practically insignificant as factors in ordinary ventilation by Pettenkofer. As the third change, the production of organic substances associated with the body odor was found to be also of minor importance, attention was finally focused on the last two changes, the increase in temperature and humidity. As far back as 1883, Hermans of Amsterdam arrived at the conclusion that the harmful effects of bad air were due, not to its chemical, but to its physical properties; and in 1905 Flügge and his associates at Breslau definitely and clearly formulated the modern concept of ventilation, a concept expressed by Prof. F. S. Lee in the succinct

[2] Teachers College, Columbia University, Contributions to Education No. 157, New York, 1924.

formula that the problem is essentially physical, not chemical, cutaneous, not respiratory. It is universally recognized today that the harmful effects of bad ventilation (aside from the presence of industrial poisons and industrial dusts) are no more the result of hypothetical morbific matter than of changes in concentration of oxygen and carbon dioxide. They are due to the effects exerted upon the heat regulating mechanism of the body by high atmospheric temperature, abnormal humidity and lack of air movement.

The conclusions of Flügge have been amply and universally confirmed by Hill and Haldane in England and by Benedict and the New York State Commission on Ventilation in the United States.[3] In one form or another these various investigators have shown that a group of subjects enclosed in an experimental chamber and suffering from the familiar effects of bad ventilation can in no way be relieved by permitting them to breathe fresh outside air admitted through a tube but can be completely relieved by cooling the vitiated air of the chamber in which they are imprisoned. Morbific matter has gone the way of the miasms of Hippocrates and the only effects which can be traced to chemical vitiation are slight interference with appetite and inclination to physical work due to the psychic effect of body odors. These latter, however, only appear with concentrations of some 20 parts of carbon dioxide equivalent to an air change of 5 cu. ft. per person per minute, and are entirely subsidiary to the thermal influences which constitute the major problem of ventilation. In the Breslau work it was found that subjects exposed to concentrations of 1.0 to 1.5 per cent carbon dioxide (100 to 150 parts per 10,000), with all the accompanying *morbific matter* were perfectly happy and showed no obvious physiological symptoms and no decrease in efficiency, so long as the experiment chamber was kept cool.

On the other hand all of this work has tended to emphasize the very serious effects of even slight degrees of overheating upon the physiological state of the human body. The average individual produces by his vital oxidations from 100 to 400 calories of heat per hour, depending upon the extent of physical exertion. This heat must be given off to the surrounding air at a rate which would normally vary very widely with the temperature of the atmosphere. Yet, by one of the most complex regulative mechanisms of the human body, these processes are so beautifully balanced that the actual body temperature does not vary in health more than a degree on either side of the normal (98.6 deg. fahr.).

At low temperatures this regulation is in part, but only in small part, accomplished by an increase in heat production; at high atmospheric temperatures there is no such adaptation, the heat production within the body being actually increased beyond a certain point, as your Pittsburgh studies have shown. It is, then, the rate of heat loss which varies and which is the chief factor in maintaining the body temperature at a fixed level. In a hot room, the tiny blood vessels of the skin expand (the face becomes flushed) and bring a large amount of blood to the surface of the body to be cooled. When passing into cold outside air, the skin blood vessels contract, the blood is sent into the inner organs and the cooling effect of the air upon it is thus correspondingly reduced.[4] This is the chief regulatory process which operates at atmospheric temperatures below 50 deg. As the temperature of the air rises, a new factor comes in, the increased

[3] For full details of the New York studies and for a review of earlier work see Ventilation: Report of the New York State Commission on Ventilation, E. P. Dutton Co., New York, 1923; and Fresh Air and Ventilation, by C.-E. A. Winslow, E. P. Dutton and Co., New York, 1926.

[4] After long exposure to cold a secondary reaction occurs which produces a dilation of the skin blood vessels in the exposed parts (the rosy cheeks of a person who has been out in nipping air). This serves as a protection of the part in question against freezing.

production of sweat, which is evaporated (if the air be not too humid) with the absorption of heat which always accompanies the change of a liquid to the gaseous form.

The primary effect of high atmospheric temperature is, then, to dilate the tiny blood vessels of the skin and to concentrate the blood flow in them at the expense of the inner parts of the body. In part, the feeling of discomfort and lassitude experienced is probably due directly to anemia of the brain and other internal organs consequent on this cooling of the blood in the capillaries. Furthermore, habitual exposure to such conditions leads to a lowered tone of the whole heat-regulating mechanism and an inability to respond to the demands which may be put on it, and in this way exerts a profound and important influence upon susceptibility to respiratory infections.

With only slightly excessive atmospheric temperature, the body temperature of the subject rises, the heart rate and the respiration increase, and the Crampton index, a measure of the efficiency of the vaso-motor system, falls to a significant degree. The performance of physical work is markedly affected. In our New York studies, 28 per cent less was accomplished at 86 deg. as compared with 68 deg. even under conditions of maximum effort, and in a test where the subjects were stimulated to work only by a small bonus, a temperature of 75 deg. showed 15 per cent less work performed than was accomplished at 68 deg., a conclusion of the most far-reaching importance as an argument for the regulation of temperatures in the workshop and the factory. Finally, the work of Hill in England and the New York State Commission in this country has indicated profound effects of only slight degrees of overheating upon the prevalence of respiratory disease, a problem to which reference will be made in a subsequent paragraph.

During the past four years our knowledge of this subject has been extraordinarily enriched by the admirable series of studies carried out by your Society in cooperation with the United States Bureau of Mines and the United States Public Health Service at Pittsburgh. It is impossible to say too much in praise of the exhaustive and careful physiological studies made at the Research Laboratory by McConnell, Houghten, Yagloglou and others.

The result of all this has been, as has been said, to give a completely new conception of the ideals and objectives of ventilation from the physiological standpoint, a conception which necessitates a corresponding change in methods to be recommended by the ventilating engineer for the promotion of human health and comfort. Aside from those industrial conditions which lead to the production of harmful fumes and dusts, the whole problem of chemical composition of air may be dismissed from consideration and in the ordinary schoolroom or office, the presence of dust particles and of bacteria is equally insignificant. I cannot refrain from pointing out that the Synthetic Air Chart which has been advocated by members of your Society for estimating the healthfulness of a given atmosphere is somewhat misleading in its failure to distinguish between what is important and what is unimportant. Variations in carbon dioxide and air supply and bacteria (within the limits reached in practice in the schoolroom and the ordinary workroom) have little or no significance from a biological standpoint and the number of dust particles present in the air may be equally unimportant or may be profoundly significant, depending on the particular type of dust concerned. The one problem of universal and supreme importance is the problem of temperature, and anything which tends to obscure and mask this factor can only mislead both the engineer and the physiologist. Good air, so far as the schoolroom is concerned, is air which has a temperature of 66–68 deg. with a moderate relative humidity and a moderate, but not excessive degree of air movement. If these

conditions are realized in practice, the air of the schoolroom in an overwhelming majority of instances can be pronounced to be good. If they are not realized, the carbon dioxide content, dust and bacteria are of little practical moment.

If these conclusions are sound, and so far as I am aware they are now accepted by every physiologist and physician who has made a study of the subject, it is obvious that standards of ventilation based on the Pettenkofer theory of dilution must be fundamentally revised. Ventilation in the modern sense is conceived primarily as a procedure for removing the excess heat produced by the human body and replacing it by fresh air that is cool but not too cold. The amount of air needed for this purpose will obviously bear no necessary and direct relation to the number of persons in a given confined space unless we also take into account the opportunity for direct heat loss through walls and ceiling. Under certain conditions, as for example in an interior auditorium with no appreciable heat loss, the standard of 30 cu. ft. per minute will prove substantially correct. An average adult gives off, as a result of oxidations within the body, approximately 400 B.t.u. of heat per hour and this is almost exactly the amount of heat necessary to raise the temperature of 30 cu. ft. of air from 60 to 70 deg. In factory work rooms where there are special heat sources such as forges, furnaces and annealing ovens, the amount of air necessary to maintain good ventilation may be materially more than this. I have in mind a particular annealing shop where 30 changes of air per hour were effected with notably successful results. On the other hand where the room is relatively small and has one or more outside walls the necessary air change may be materially less. It is this condition which obtains in the ordinary schoolroom and it is in connection with school ventilation that a radical revision of our earlier view points is most clearly indicated.

When the New York State Commission on Ventilation began its work ten years ago the major problem before it was obviously to determine whether the then accepted system of plenum fan ventilation was better adapted than any other to the maintenance of good air conditions in the school. The Commission began its work with no prepossessions in favor of any type of ventilating equipment. Personally, I was somewhat inclined to believe that the plenum system had been needlessly criticized and rather expected that our study might lead to its vindication. We quickly discarded as ineffective the attempt to ventilate the school by the use of windows alone and concentrated our attention upon two procedures which preliminary work indicated to be most promising. The first of these was the ordinary plenum system and the second was a modified gravity system of ventilation involving the admission of cool air over slanting window boards with tempering radiators below the windows, and the removal of warm air from above by gravity exhaust ducts. It is of interest to note that the latter procedure is no radical innovation but is essentially the method used by Tredgold and Reid in England and in this country some 75 to 100 years ago. The conditions necessary for the success of the window-gravity method of ventilation are outlined by the New York State Commission as follows:

(*a*) Radiators must be located beneath the windows and extend for the full width of the windows from which the air supply is to be derived. These radiators, because much larger than those customarily installed in ordinary plenum systems, should be either automatically controlled by intermediate acting thermostats or equipped with fractional or modulating hand-controlled valves, placed at the top of the supply end of the radiator. Even when automatic control is included it is best to supplement it by the provision of hand control as well; and standard metal radiator shields are desirable to protect the pupils nearest the radiators from excessive heat.

It is to be noted that the use of intermediate acting thermostats or modulating hand-controlled valves presupposes the use of a vapor vacuum steam heating system.

(*b*) Deflecting boards of some satisfactory type should be placed at the bottom of the windows. Devices which include small box-like openings, and devices which involve the use of filtering screens of various types are undesirable. A plane glass deflector one foot high is fairly satisfactory, but the best results may be obtained by the use of curved vane deflectors which secure the most equable distribution of the air. The windows in the use of this method should open from the bottom and not from the top.

(*c*) In order to avoid certain practical difficulties it is recommended that windows should be so constructed as to open easily from the bottom, and that window shades should be firmly attached to the window frame, the best arrangement being that which includes two shades anchored midway between top and bottom, one to be pulled upward and the other downward, these shades being so guided by cords and pulleys as to avoid the shaking of the screens by the incoming air flow.

(*d*) Exhaust ducts having a total area of not less than 8 square feet for an ordinary schoolroom should be provided on the wall opposite the windows. These exhaust openings should be conveniently dampered so that their area may be adjusted to varying weather conditions. The exhaust ducts should be carried up through the interior of the building so as to avoid chilling and the tendency to back drafts should be further reduced by placing an aspirating cowl on the opening at the roof and perhaps by placing heating coils in the exhaust duct.

(*e*) The schoolroom should not be overcrowded. The successful results reported by the New York Committee with this method of ventilation have been obtained with a cubic space allowance of 250 cu. ft. per second grade child (39 children in an ordinary schoolroom) and with a cubic space allowance of 310 cu. ft. per sixth grade child (31 children in an ordinary schoolroom).

(*f*) A large thermometer with 68 deg. fahr. clearly indicated as a danger point should be displayed in a prominent position on the teacher's desk.

In the course of studies extending over a period of over three years, in scores of different school buildings, we came to realize that the ordinary plenum system of school ventilation and this window-gravity system, as defined above, were both reasonably adequate, according to generally accepted standards, but differed substantially in two respects. In the first place the gravity method had a materially lower air flow (some 10–20 cu. ft. per minute through the exhaust duct) as compared with the plenum method. The carbon dioxide was therefore higher (averaging 6–11 parts per 10,000) but the lessened aeration was still amply sufficient to avoid objectionable odors.[5] In the second place, the gravity method was characterized by a slightly but materially lower temperature. With the plenum system it was necessary to keep the schoolrooms at an average temperature of $68^1/_2$ deg. in order to protect the children against the chilling effect on the face of a powerful draft of air. With the gravity method the schoolrooms could be kept at an average temperature of $66^1/_2$ deg.

According to your Research Laboratory studies these two atmospheric conditions, $68^1/_2$ deg. with a high air flow and $66^1/_2$ deg. with low air flow, are substantially equivalent in their power of removing heat from the body. As a matter of practical experience, however, it was the unanimous opinion, of teachers and of expert observers alike, that the cool room with the lower air flow was more agreeable than the warm room with its change of 30 cu. ft. per minute. This phenomenon is explained primarily by the fact that the high temperature necessary to protect the face against rapidly moving air produces an overheating,

[5] It should be noted that while the air flow through the exhaust duct was only 10–20 cubic feet per capita, the total air change, as indicated by carbon dioxide figures must have been 12–30 cubic feet per capita, the additional air change being due of course to leakage. As a rule, however, the window-ventilated rooms had over 7 parts carbon dioxide corresponding to a total air change of less than 25 cubic feet.

uncomfortable for the clothed parts of the body; although the slight and stimulating variability of the atmosphere of the gravity-ventilated room no doubt plays a part in the process. In any case the result was clear. The rooms ventilated by the window gravity method were not only quite as satisfactory as those supplied with 30 cu. ft. of air per minute but were more satisfactory from the standpoint of the comfort of the occupants and as will be seen later they also exerted a highly beneficial effect from the standpoint of the prevention of respiratory disease.

If these results are accepted as I believe they must be, as demonstrating that a positive system of fan ventilation, supplying 30 cu. ft. of air per minute, is unnecessary in an ordinary schoolroom, we are faced with the fact that existing legislation requiring the installation of such systems is the cause of a large and indefensible waste of public funds. I have estimated, on the assumption that only one-third of the new school construction in the United States is equipped with mechanical ventilation, that over three million dollars a year is needlessly spent in the installation of equipment of this type[6] and if the fan systems are operated (which they frequently are not) there is a further waste of money burnt up and poured into the circumambient atmosphere, which amounts for New York State alone to $200,000 a year.

If this were all, if the harm done by outworn theories of ventilation were limited to the pocket book the matter might be dismissed as one to be settled between appropriating bodies and their own consciences. There is a much more serious problem involved, however, as the New York studies have made manifest. The maintenance of a temperature over 68 deg., which is an essential and unavoidable condition of the 30 cu. ft. per minute standard, is not only unnecessary but positively harmful. In our studies we compared in the most exhaustive way, and during two successive winters, the effect on 2500 to 3000 children of three types of actual school-room ventilation. The first group of children were in rooms ventilated by window inlets and gravity exhaust and kept at a mean temperature of 59 deg. The second group were in rooms ventilated by window inlets and gravity exhaust and kept at a mean temperature of 66½ deg. The third group were in rooms ventilated by fan supply and gravity exhaust and kept at a mean temperature of 68½ deg. When the records for the two years were analyzed and averaged it appeared that the amount of respiratory sickness in the 59 deg. rooms and the 66½ deg. rooms was essentially the same; while the 68½ deg. rooms showed an 18 per cent excess of absence due to respiratory sickness and a 70 per cent excess of respiratory sickness among pupils in attendance. After the most careful study of social and economic conditions and of all other factors bearing on the case, there seemed no escape from the conclusion that even the slight degree of overheating associated with an average temperature of 68½ deg. had exerted a profound and harmful influence on the susceptibility of the children to respiratory disease.

Thanks to the researches of Leonard Hill, confirmed and extended by the New York State Commission, we understand, to some extent at least, the mechanism of the process by which overheated rooms in winter produce such disastrous results. In a warm room, the tissues of the nose and throat are normally swollen and moist and full of blood. When passing to the cold outdoor air these tissues become compact and dry and their blood vessels contract. In persons habitually exposed to a high room temperature, however, this normal adaptive response fails. The blood vessels always contract but the tissues remain swollen and moist,

[6] See *American School Board Journal*, June, 1925, LXX, 45.

and such a condition furnishes ideal opportunities for the invasion of the germs of respiratory disease.

We find ourselves, then, face to face with the fact that plenum ventilation providing 30 cu. ft. of air per minute per child, in the ordinary schoolroom, is not only economically wasteful but fundamentally harmful to the health of the school child since it implies and involves an overheated atmosphere; and if such a degree of air supply is needless the system of fan ventilation itself becomes unnecessary. I believe, therefore, that the state laws and regulations requiring the installation of systems of this type, wise and judicious as they seemed in the light of the knowledge of 25 years ago, are today wholly unjustified and harmful, and that it is the duty of all of us to see that they are promptly repealed.

It must be clearly understood, however, that the conclusions I am enunciating bear only on the average schoolroom, so situated that the application of the system of modified window ventilation can be safely and conveniently applied. In the auditorium and in the large office or crowded factory, workroom conditions are wholly different. In a room containing much more than 50 people, ventilation by the modified gravity system would generally prove inadequate in view of the difficulties of securing a properly distributed air change throughout the room and in view of the excess of heat production within the room as compared with heat loss through its walls. For such an occupied space, plenum ventilation offers as I see it the only possible remedy and in dealing with such rooms the standard practices of your profession have proved themselves adequate, satisfactory and economical. I look for an unprecedented future development in the field of technical industrial ventilation as industries come to realize the profound influence upon efficiency of the overheating which is now so general in the factory and workshop. Vernon's studies in the tin plate mills of England showed for example a reduction of 13 per cent in summer output in badly ventilated plants as against only 3 per cent in plants provided with adequate artificial ventilation. In dealing with such problems as this, frankly and definitely on the basis of heat removal, your profession can render a great service to industry and to the public health as well.

In factories where industrial poisons such as carbon monoxide and lead dust, and benzol are present, and above all in industries where susceptibility to tuberculosis is increased by the presence of silica dust, there is another rich field for the ventilating engineer which is ripe for the harvest. In a certain axe factory in Connecticut the tuberculosis death rate among grinders and polishers was for a period of 20 years, ten times as high as the rate which existed among their fellows not exposed to the same deadly atmosphere, and the reports of the Registrar General of England and Wales show that of the eight industries showing a tuberculosis rate more than twice the normal, six were exposed to the inhalation of silica dust. In such cases as this the installation of exhaust systems with properly designed hoods, adapted to the particular machine which produces the dust, and with ducts and fans arranged to maintain adequate suction velocity, is a task of the first importance and one which calls for the exercise of the highest skill of your profession.

In dealing with these latter problems which I have discussed the ventilating engineer needs only to go forward along the lines which have been so well worked out during the past half century. In the auditorium and in the large and crowded office and workroom, above all where industrial fumes and dusts are present, it is necessary to secure an ample air change and to secure it by the use of plenum or exhaust ventilation of a positive kind. In the schoolroom, however, the studies of the physiologists have made it abundantly clear that such excessive air change

is neither necessary nor desirable and that the health of the school child, as well as economy in the use of the public funds, indicates a gravity type of ventilation with window inlets as in general the procedure to be followed. To quote from a resolution unanimously adopted by the *American Public Health Association*, the professional association of American sanitarians, representing not only health administrators but laboratory workers and sanitary engineers as well:

"*Whereas* hundreds of thousands of dollars are wasted every year on this continent in the installation and operation of systems of school ventilation which are not only not beneficial but are positively harmful to the health of school children. And whereas

In the light of current knowledge, the supply of as large an air volume in schoolrooms as 30 cubic feet per minute, per capita, is necessarily accompanied with dangerous overheating of the schoolroom in order to avoid resulting drafts. And whereas

The use of ozone and other chemicals for treating schoolroom air has little or no scientific justification and little or no practical value;

Resolved: That the system of ventilating schoolrooms by fresh untreated outdoor air, admitted at the windows with gravity exhaust ducts for removing vitiated air from near the ceiling, is the most generally satisfactory method of school ventilation; and

That state laws and city regulations interfering with such scientific and economical methods of school ventilation should be repealed in the interests of the public health."

In the task of remodeling health legislation along the lines of modern knowledge we ask you for your sympathy and your assistance. In 1900 you were right in supporting legislation requiring plenum ventilation in the schoolroom, for you were acting on the basis of the best knowledge then available. Through no fault of yours, and through no fault of the physiologists, but merely an account of the inevitable and steady progress of experimental science the rational basis for this type of regulation has disappeared. To attempt to maintain it in the face of the proven facts of physiological science may delay progress for a time; but its ultimate result will be only to bring discredit on those of us who remain blind to the new information at our disposal.

DISCUSSION

RESEARCH HAS DETERMINED MOST DESIRABLE AIR CONDITIONS

DR. W. J. MCCONNELL: I have listened to Prof. Winslow's paper with much interest and am impressed, as I always have been after hearing him speak, with his sincerity and clearness of expression. Ventilation is a subject which has been closely linked with Prof. Winslow's name for a number of years and his studies together with those of his associates are well and widely known. I believe that Prof. Winslow has done as much as any other man to stimulate research and discussion of the problems involved in ventilation and I venture the assertion that he will only be too glad to welcome any new evidence leading to their solution.

Some five years ago when I was assigned to take part in the studies, still in progress, which this Society, cooperating with the U. S. Bureau of Mines and the U. S. Public Health Service, is conducting in Pittsburgh, I soon learned through

Dr. Sayers and members of the research staff of the Society that the object of that study was identical with that mentioned by Prof. Winslow; namely, the determination of those conditions of the atmosphere best suited for human health and comfort. During this period my association with members of this Society, taught me to admire this great organization of engineers for their leadership and support of this study. Here members of the medical profession and the engineering profession, with the aid of members from the other sciences, work in harmony with but this single object in view. This has brought forth favorable comment from different sections of the world.

Not long ago I was interested in reading an article by T. R. Wilson, secretary of the Industrial Fatigue Research Board of London, of his impression on a visit to the United States. He states that while American practice in some respects falls short of the English (we would expect that), America is far ahead of England in some respects; one being in the cooperation of the engineer and the technician with the physiologist and psychologist, an alliance which in his view is essential for real progress, and he cites this cooperation at Pittsburgh.

Again, we do not hold any different theories. We are all agreed that the harmful effects of bad ventilation under ordinary conditions, such as in schoolrooms and public buildings, are due to the physical constituents of the atmosphere. It is, therefore, fair to assume that if we are able to control these three physical air factors and combine them in such a way that they will best promote normal heat loss upon the human body, that should be the desirable condition. The experimental work of Pittsburgh has shown that quite a number of combinations of these three physical factors will accomplish this. These studies have likewise proven that at present no single instrument exists which will measure or indicate the comfort of an atmosphere; neither the dry bulb, the wet bulb, the dew point nor the Kata will give this information.

Zone of Comfort Known

However, the work at Pittsburgh has developed a thermal index of the atmosphere known as the effective temperature scale which indicates the comfort of a variety of atmospheric conditions. It has been shown that within this effective temperature scale there lies a zone of comfort. This zone of comfort lies between 63 and 71 deg. effective temperature.

The question which arises in my mind is whether or not there exists an optimum temperature for a large number of individuals. May it not be that each individual has his own optimum temperature depending upon his physical condition, the condition of his skin, the amount of clothing worn, the amount of work accomplished and no doubt other factors; and that this optimum condition may change slightly from day to day and very slightly from the optimum condition of other individuals?

For instance, I have noted that among subjects in the temperature chamber that those who declared a certain temperature a little too warm soon became drowsy and sleepy, while under the same conditions other individuals who declared the conditions just right remained alert. I have noticed that certain conditions which seemed very satisfactory to me on one occasion did not have the same effect on another. So it may be that a fluctuating temperature within this zone of comfort (and I believe Dr. Sayers and others share this opinion) may best meet the demands of a large number of individuals. I understand that experiments along this line are now in progress at the Research Laboratory in Pittsburgh.

Temperature No Index to Respiratory Diseases

Just a word about temperature and respiratory diseases. I do not believe that we are justified in attaching too much importance to temperature conditions affecting respiratory diseases. Physical defects of the human body such as enlarged tonsils, enlarged terbinates, deflected septums and other defects have shared the distinction of contributing to respiratory diseases. If we compare mortality per 100,000 from respiratory diseases in this country, where the inclination seems to be to overheat the homes, with those of England and Wales, where certainly the reverse is true, we find that England and Wales have the higher mortality.

Again, during a residence of a year and a half in England and France, I was unable to notice any difference at all except that the instructors there told me that they had so many respiratory diseases among children because the temperature was too cold. So I doubt whether in view of the present information we can attribute so much to the temperature or small rises of temperature.

Ventilation Standards Needed

As I see it our big problem at present is to determine a standard of ventilation and I believe this can best be done by a cooperation between the engineer and the professions interested. There at Pittsburgh the question never arose as to how can we obtain a certain atmospheric condition. The engineers are already masters in their art. The question always was, "What atmospheric condition do you want?" I question whether, knowing these desirable conditions, any one individual can maintain these conditions by opening and closing windows. At any rate, once a standard is established, I am content to leave the matter of maintaining it to the engineering profession.

AN ANALYSIS OF VENTILATION

PERRY WEST (WRITTEN): I feel that we, and the world at large, are greatly indebted to Prof. Winslow, not only for this remarkable paper, but for the still greater amount of thought and energy which he has devoted to this subject for the past 10 years. I am especially impressed with the simplicity and conclusiveness of the solution which he has offered, to this age old problem.

There has always been a strong appeal in the hope that most of our difficulties might be reducible to the terms of simple problems, susceptible of simple answers. I have often thought how splendid it would be if the churches could cast aside all of their creeds, dogmas and other complexities and after first teaching men to be honest and how to think and live right, add all of these other things, which are good, unto themselves.

What a relief it would be if we could do away with much of the complex machinery of governments, with its multiplicity of laws restricting personal liberty, and after first teaching men to obey the golden rule, add such of these other things as are essential. The great majority of us might welcome the abandonment of many of the complexities of modern social life and after getting back to the enjoyment of a few homely pleasures, add such of these other things as we wish.

It is not meant by these illustrations to suggest disparagement or curtailment of the items of real progress or improvements in modern civilization, but rather to recall to mind that there are many things which require our serious study and attention, and to give a better idea of some of the reasons why a thesis such as Prof.

Winslow is offering is accepted and espoused by so many of our good citizens and especially by the press and the popularity-courting trade journals.

We are indebted to Prof. Winslow for such courage of conviction as he has shown in coming out and fighting for so definite and conclusive a settlement of this thing which is so vital to the health, comfort and economy of mankind. We are here today to consider and discuss this thesis of Prof. Winslow's in all fairness and reason and with the one thought in mind of making the best possible use of it in the progress of this science and with it the health and comfort of all people. It seems to me that time and experience will determine, more than anything we may do here today, the final merits of his work, but it may be possible for us to expedite this determination. At all events this definite challenge will stimulate an activity, which we have stood in great need of for years.

I have made a brief analysis of Prof. Winslow's paper and while much of this, as well as some of the other discussions, may disagree with his theorem, I trust that we shall all be able to state our opposing views with the greatest courtesy and consideration for a guest of such learning and ability, who has had the courage to bring this battle here into the camp of the enemy.

The first half of Prof. Winslow's paper is devoted to a discussion of the worn-out carbon dioxide and human effluvia theories on ventilation and to the putting forward of the evils of overheating to the general disregard of all other factors.

While we shall not consider that it is the intention and purpose of this part of the paper to convey the idea that the members of this Society are ignorant of the fact that these theories are no longer the basis for proper standards of ventilation, it is nevertheless true that most laymen in reading this part of his paper would come to the conclusion that heating and ventilating engineers today are still clinging to these worn-out theories and that our standards are based thereupon.

Engineers Discarded CO_2 Theory in 1911

When Dr. Winslow states that, *the science of ventilation as it has been understood by our profession from the time of Billings and Woodbridge almost to the present day has been based on the conception of the German hygienist, Von Pettenkofer,* I do not believe that he intends to ignore the important work which was started at the 1911 annual meeting of this Society, where Dr. W. E. Evans of the Chicago Health Board and Dr. Luther H. Gurlock of the Russell Sage Foundation brought the first real indictment against the practical results of these theories of ventilation, and it was definitely stated that the overheated dry atmosphere of our best mechanically ventilated buildings was enervating, deleterious to the internal membranes and otherwise detrimental to the health and comfort of the human occupants of such buildings.

Nor do we perhaps believe that he wishes to ignore the important work along the very line of getting away from these chemical theories into the physical ones, which was started in this country as a result of this meeting and which have been carried on almost continuously since, by such men as Dr. Leonard Hill, Dr. E. V. Hill, Dr. F. S. Lee, Dr. E. L. Scott, Dr. Wolf Freudenthall, Dr. M. A. Miller, Dr. Gerald Cocks, Dr. F. W. Eastman, Dr. G. W. Jones, W. P. Yant, Dr. W. J. McConnell, W. H. Carrier, Dean John R. Allen, Dean F. Paul Anderson, F. C. Houghten, Jay R. McColl, E. S. Hallett, J. I. Lyle and many others.

As a matter of fact we go much further back than Hermans (in 1882) to LeBlanc (in 1842) and Bernard (in 1857) with our knowledge that these old theories were seriously questioned.

Responsibility in Present Day Conditions

The fact, however, that these earlier physiologists did not follow up their part of the work in defining the proper standards of ventilation from the physiological standpoint was responsible for the conditions which were found to exist in 1911 and we might add that this same failure on the part of the physiologists from that day to this is more responsible for the situation as it exists today than any other one thing.

We say this because the heating and ventilating engineer has been continuously improving and refining the mechanical apparatus and has always stood in a position to produce any desired condition of indoor atmosphere, but the doctors and physiologists have never been in a position to define definitely just the conditions required for proper ventilation.

The work of the New York State Commission on Ventilation was started about five years later and as we all know collected a great mass of data which, with proper interpretation, has been and will continue to be of great value. We should not wish to detract one iota from the worth of this great work, nor do I wish to be discourteous when I say that in order to keep the records straight, I think it should be stated here that we are in practical agreement with the only two definite findings of the New York State Commission on Ventilation, *i. e.*, that the older carbon dioxide theory is substantially wrong and that overheating is detrimental, but that the leading members of this Society knew of and were on record as to these revised theories of ventilation several years before the findings of the New York State Commission on Ventilation were made public about 1918.

Synthetic Air Chart a Scientific Standard

Another observation I wish to make is that Prof. Winslow seems to misunderstand the *modus-operandi* of the Synthetic Air Chart when he states that it fails to distinguish between what is important and what is unimportant. I believe that if he thoroughly understood this chart he would immediately see that this is just what it does do. It is the only measure which we have today that in any way attempts to afford a scientific means of including all of these factors and giving to each a distinguishing and comparable value. This standard for measuring the quality of ventilation is the result of much hard work and thought on the part of a number of the leading members of this Society and a number of the leading doctors and physiologists throughout the country and has been officially adopted by this Society as its standard. It is not, therefore, simply a standard advocated by some members of this Society as Prof. Winslow has evidently allowed himself to believe. The values for the various factors are always subject to revision as new research may dictate, but I do not see how the principle of this standard could be so easily laid aside by any of us who are seeking the best light to be had upon this subject.

I think the most important fact to be drawn from this is that, if a man of Prof. Winslow's caliber and contacts so far misunderstands our standards and aims, it is high time that we try to make ourselves better understood. I cannot refrain from comparing with this the very indefinite standard which Prof. Winslow offers of *a temperature of 66 deg. to 68 deg. with moderate relative humidity and a moderate but no excessive degree of air movement.*

In summing up the first half of Prof. Winslow's paper it seems to me to cover the following:

1. A plea for close and cordial mutual understanding between physiologists, physicians and engineers, the establishment of standards by the physiologist and the devising and maintaining of the mechanical apparatus by the engineer.

To these high aims I think the engineers of the Society will all heartily agree.

2. The explosion of the older carbon dioxide theories on ventilation, which theories were exploded and discarded about 15 years ago, and in this we have been in agreement with the Doctor's theories for a number of years.

3. The total elimination of a definite quantity of air supply, air distribution, dust, bacteria, odors, poisonous gases and other injurious substances and only an indefinite inclusion of humidity and air motion, with the dry-bulb temperature as the only real index to the standard of ventilation which he proposes. This I believe, as Prof. Winslow states himself, really reduces the problem to one of heating rather than ventilation, so that after all we really have no ventilation problem left. To this we cannot, of course, agree in any way, but I shall leave its further discussion to others here who will undoubtedly wish to speak upon these points.

4. The elimination of all other standards including the synthetic air chart. I believe there will also be enough discussion upon this.

5. An expounding of the theorem that 30 cu. ft. of air per min. per pupil in public schools is wrong, with the suggestion that this and existing state laws based thereon are the result of obsolete engineering and with the further suggestion that our present aims and standards advocate these conditions. Here again I might say that it is rather amazing to find any one of the different factions of this undertaking, who are supposed to cooperate, so far misunderstand the simplest fundamentals of what another is trying to do. It would seem that even a casual observation of the present aims and standards of this Society would show that nothing could be much further from the facts. In the first place, as Prof. Winslow says, the original standard of 30 cu. ft. was proposed by the physiologists. In the second place, I believe that we were the first to get away from this and nowhere in our standards of today is there any reference to the quantity of air to be supplied. It is quite true that any one who attempts the physical job of providing ventilation (be he engineer, doctor or physiologist) must first have the quantity of air required to be handled. This applies whether we use window ventilation or mechanical ventilation; for with windows we must know how much air is to be handled in order to figure the radiation and the size of the exhaust ducts, window inlets, etc. With mechanical ventilation we must know the same thing because no apparatus is rated upon any other basis.

When Prof. Winslow says that 8 sq. ft. of exhaust duct are required for a school room to accommodate 35 pupils he must base this upon the fact that a certain minimum amount of air is to be handled per pupil and, as a matter of fact, with a velocity in this duct of only 200 ft. per min. the doctor would have over 45 cu. ft. per min. per pupil. The same applies to the amount of window opening to be provided so that I think, try as we may, it will always be hard for any of us to get away from the quantity of air to be handled.

6. And finally the abandonment of the establishing of a standard by doctors, except for the indefinite one mentioned above, and the solving of the problem by fixing the methods and apparatus, which was, in the first place, to be left by Prof. Winslow to the engineer.

In the second half of the paper I find that Prof. Winslow steps almost entirely away from the standards of ventilation except for the reference to studies made by the New York State Commission where the effects of window-ventilated rooms at 66½ deg. are compared with mechanically ventilated rooms at 68½ deg. with the statement that the mechanically ventilated rooms required to be kept at this higher temperature in order to make them comfortable on account of the powerful draft of air caused by the delivery of 30 cu. ft. of air per minute per pupil with this system, as against the 10 to 20 cu. ft. delivered with the open window method.

Antiquated Equipment Used in N. Y. Tests

We all know that the mechanical systems in all but one of the schools used for these tests were antiquated and not at all suitable for making any comparisons between window and mechanical ventilation, but granting all of this, it is hard to understand how the conclusion could be seriously drawn that the powerful draft could be responsible for requiring this difference in temperature.

Powerful Draft Theory Exploded

In a standard schoolroom which is about 30 ft. long by 25 ft. wide and 12 ft. high. Thirty cu. ft. of air per pupil for 50 pupils equals 1500 cu. ft. of air per minute. If this air is all admitted along one of the long sides near the ceiling and allowed to travel across the upper part of the room to the opposite wall and then back across the lower part to exhaust registers near the floor the average velocity of the air is about 8 ft. per min.

Air Motion Necessary for Comfort

With window ventilation admitting only 10 cu. ft. per pupil and flowing across the entire cross section, the average velocity would be about $1^1/_2$ ft. per min. I have never seen any scientific studies on air motion that would differentiate between the physiological effects of 8 ft. and $1^1/_2$ ft. per min. velocity and surely 8 ft. per min. could not be considered a powerful draft. The velocity in these mechanically ventilated rooms may have been considerably in excess of the above figures but why should we work into difficulties like these instead of out of them and why for such a reason should such a comparison between methods of ventilation be made and used as a basis for the guidance of our people. It is further suggested that this idea is substantiated by our Pittsburgh studies, where it is shown that these two atmospheric conditions of $68^1/_2$ deg. with high air flow and $68^1/_2$ deg. with low air flow are substantially equivalent in their power of removing heat from the clothed body.

It is not stated as to what is meant by high and low air flows but if the above figures may be used these studies would show no appreciable difference in the effective temperature and here again I think that we can say that we have not succeeded very well in making our work understandable to our collaborators.

Further on we have a comparison between window ventilated rooms at from 59 deg. to $66^1/_2$ deg. and fan ventilated rooms at $68^1/_2$ deg., bearing upon respiratory diseases, with the conclusion that the children could be kept perfectly comfortable in the lower temperatures of the window ventilated rooms while the higher temperature was required in the fan-ventilated rooms on account of these powerful drafts.

It is stated that the rooms ventilated by the window gravity method were not only quite as satisfactory as those supplied with 30 cu. ft. of air per min. but were more satisfactory from the standpoint of the comfort of the occupants and also exerted a highly beneficial effect from the standpoint of the prevention of respiratory diseases.

Naturally the lower temperatures with their higher and more nearly normal humidities would exert this beneficial effect, but why again associate the higher temperatures with fan systems as a part of the physiological standards of ventilation.

Best Temperatures for Workers

The only further comment here is that I should like to know (after about 10 years of experience with school systems) how to make teachers and children comfortable in a temperature of 59 to $66^1/_2$ deg. and why it is that the most recent studies of factory workers is showing that men do their best work at about 70 deg. and 40 per cent humidity and women at 78 deg. and a correspondingly lower humidity.

I may have overlooked some of the important points, but I have tried to cover all that I saw in the paper, but the next thing I see is this, "If we accept these

results, as I believe we must, as demonstrating that a positive system of fan ventilation supplying 30 cu. ft. of air per min. is unnecessary in an ordinary school room, we are faced with the fact that existing legislation requiring the installation of such a system is the cause of a large and indefensible waste of public funds."

Prof. Winslow estimates that over $3,000,000.00 is spent per year for the needless installation of mechanical ventilation throughout the schools of the United States, and if these fan systems were all run it would entail a further waste of $200,000.00 per year.

No detailed figures are given and it would, of course, entail much more time and study than can be given these matters here to arrive at any definite conclusion so far as these claims are concerned. I do not think, however, that anything could be much further from the truth, which I think can be shown by a few simple mathematical calculations.

Some Actual Cost Figures

The heating of an average schoolroom, independent of its air supply in our cooler climates requires about 100 sq. ft. of direct radiation. If we add the necessary radiation for heating the minimum of 10 cu. ft. of air per min. per pupil for window ventilation it will require about 225 sq. ft. of direct radiation. *This will about double the cost of our heating system.*

Adding to this the increased cost of building due to increasing the classroom space from 200 cu. ft., ordinarily required with mechanical ventilation, to 280 cu. ft. required for window ventilation, we have 40 per cent increase in the classroom cubiture which represents an *increase of 15 per cent in the cost of the entire building.*

The cost of the heating, disregarding the air supply, is 8 per cent of the cost of the building and the cost of *mechanical ventilation is 7 per cent of the cost of the building.*

Taking the 8 per cent and adding to it another 8 per cent for increasing the radiation sufficient for window ventilation and then adding 15 per cent for the added cost of the building we have a total of *31 per cent for the window ventilated school.*

Taking the 8 per cent for heating and adding *7 per cent for ventilation* we have *15 per cent as the comparative cost for the mechanically ventilated school.* This not considering added costs for larger exhaust ducts, window ventilators and the fact that east rooms must be planned against with window ventilation, as recommended by the N. Y. State Commission's report.

The above comparison is on the basis of our colder climates where the heating and ventilating cannot be done by a fan system without direct radiation. In some of our milder climates, such as around St. Louis, where the ventilating system does the heating also, the cost for heating and ventilating apparatus is not much more than 8 to 10 per cent of the cost of the building.

So that the comparison is still more in favor of mechanical ventilation.

As to the yearly cost to operate with and without mechanical ventilation: theoretically, it should (in our colder seaboard climates) require 2 tons of coal per classroom per season for heating alone; 4 additional tons for ventilation, making a total of 6 tons for heating and ventilating where the air is all taken in from the outside. With proper recirculation the coal required for ventilation may be cut to 2 tons making a total of 4 tons to heat and ventilate.

Operating Expense for Heating and Ventilating Schools

This is theoretical, but an analysis of the operating cost for a number of schools in one of our larger cities, over a period of three years with the ventilation in operation and a period of seven years without the ventilation in operation, discloses some very interesting facts in connection with the practical side of this question.

It was found for instance, that for 10 schools with mechanical ventilation and temperature control, 6.7 tons of coal per classroom per year were required with the ventilation running and 6.3 tons for heating the building alone without the ventilation running. In eight schools with mechanical ventilation but without temperature control, 6.9 tons per classroom per year were required with the ventilation running, and 5.7 tons for heating alone without the ventilation. For 14 schools without mechanical ventilation or temperature control 5.85 tons per classroom per year were required during the first (3 year period) and 5.75 tons per classroom per year for the second (7-year period).

It will be seen from the above that the schools with ventilation in operation required approximately the theoretical amount of coal whereas the schools without ventilation in operation required about three times the theoretical coal due to the fact that without ventilation the windows are open very much more of the time and the building is required to be heated to a much higher temperature in order to be comfortable.

Recirculation Reduces Costs

From the figures quoted, in practice, but little more coal may be required for taking care of heating and ventilating than is otherwise required for heating alone. It would be well to say, however, that we may figure 1 ton more per classroom per year at $10.00 per ton and adding to this the cost of electric current (to drive the ventilating fans) at $15.00 per year we will have a total cost of $25.00 per classroom per year for the operation of the ventilation. This may be reduced by proper recirculation and air conditioning to no addition for coal and about $7.50 for electric current.

The figures given are for schools without window ventilation and about $^1/_2$ ton of coal should be added for this, which would mean that the operating costs would about balance, except for the fact that the number of pupils in a window ventilated school is reduced from 20 to 30 per cent. This would naturally mean that the operating cost per pupil would be from 20 to 30 per cent higher in the window ventilated schools.

None of the above figures take into account the very much larger added costs in teachers' salaries and general overhead for operating a school building involved in so materially cutting down the number of pupils accommodated.

I think, as a matter of fact, that this whole subject of costs to install and costs to operate requires a great deal more study than they have ever been given as I think we generally proceed on some highly opinionated decision without any real data.

In summing up I wish to refer to the point which I believe Prof. Winslow is trying to make, which is the one I may have mentioned as being overlooked, *i. e.*, that 30 cu. ft. of air per min. per pupil are not required in our public schools, that overheating and drafts are inevitable with any mechanical system, and that our State Laws requiring 30 cu. ft. or mechanical systems should be repealed, so that school authorities can do anything they may wish, or what may be wished upon them, as far as school ventilation is concerned.

Stricter Ventilation Laws Need Revision for Health Protection

There is no question that the present laws are inadequate and perhaps faulty. In most instances they contain no provisions for the attainment or maintenance of any particular standard of ventilation, or even the operation of the plants at all after they are once installed.

A great many mechanical plants produce drafts and are subject to overheating but it should be distinctly understood, by any one at all versed in the science, that these faults are not inherent in the mechanical plant and that any desired atmospheric condition can be more certainly, more accurately and more cheaply maintained with the mechanical system than by any other means.

I do not believe that Prof. Winslow or we are prepared to say whether the 30 cu. ft. are right or wrong.

We either do or do not need ventilation in our schools and I believe we all agree that we do. Granting this, the only way to get it is to have state laws which define the requirements and the methods which shall be used for the attainment and maintenance of these requirements.

I think that we should all get together, therefore, and agree upon the proper standards, within certain limits, fixing these limits not only for the summation of the various factors involved, but for each individual factor as well. Following this I think we should agree upon the different kinds of apparatus and methods and the commercial capacities which may be employed to produce the standards required. We should formulate revised regulations to be offered for adoption in place of the present laws.

No Criticisms Accepted without a Remedy

Until this is done, and until we have new and better regulations to offer, I cannot understand where the recommendation to repeal the present laws is intended to lead.

As to the *American Public Health Association's* resolution, it is to be regretted that so prominent a body, which is supposed to lead the way in matters of health and comfort, has seen fit to destroy without offering something in a constructive way.

A further exception which I desire to take to Prof. Winslow's paper, is in regard to his plea that engineers should go ahead with industrial ventilation and keep on producing proper air conditions for manufacturing chewing gum, candy, tobacco and textiles, even eliminate dirt from the "lungs" of automobile motors, and not be concerned with the health of our school children who are allowed to suffer the tortures of stewing in their own juice and breathing unclean air while subject to the vagaries of window ventilation.

Expect Results Undreamed of Now

And now just a word about mechanical ventilation. I am not apprehensive about what might happen to mechanical ventilation in the face of this chaotic and hysterical period through which we seem to be passing. I wish to assure you that I am not, for after the smoke has blown away, I believe that we shall see the kind of equipment come forward that will produce results, never yet dreamed of.

Whether we ventilate with the window or the fan, in the office, school or home, you will find that we always do it one way. When the weather is fine we open the window or run the fan full speed and have lots of fresh air. As the winter

closes in and the weather gets bad we close the window more and more and slow the fan down.

The ventilating system of the future will do this automatically by recirculating more and more air as the weather grows bad and by proper air conditioning will keep the air pure and clean. This system will be efficient, economical, and give the maximum of comfort.

MECHANICAL VENTILATION THE METHOD OF THE FUTURE

DR. E. V. HILL: It seems rather unfair to invite Prof. Winslow here all alone to present a paper and then ask everyone to get up and jump on him. I will not throw any bouquets at him nor, on the other hand, will I speak with any animus. It seems to me that there are three points in the paper which stand out prominently. The first is that the quantitative standard of 30 cu. ft. of air per min. was in the past based on the carbon dioxide theory; and that the carbon dioxide theory having been exploded the 30 cu. ft. standard necessarily falls with it.

The second point is that 30 cu. ft. of air, as Prof. Winslow sees it, is an excessive amount to introduce into a school room and that it is necessarily accompanied by a high temperature in order to avoid objectionable draughts.

The third proposition is that the mechanically ventilated school room shows a higher average of respiratory diseases than the window ventilated room.

Very briefly I wish to submit some evidence that I believe shows each of these propositions to be very questionable at least. The carbon dioxide standard, which was commonly accepted a generation or so ago, never, as far as I can see, had any particular connection with the *quantity* of air supplied. If I read the history of ventilation correctly (and I have given it some study), it seems to me that Pettenkofer suggested, if my memory is correct, 10 parts of carbon dioxide, as a desirable standard, he thought that there were poisonous substances exhaled by the occupants of a room and suggested that carbon dioxide *might* be used as an index. Now mind you these supposedly poisonous substances have never been isolated. No one knew what they were and of course there was no information possible as to their toxicity. Therefore, it would be manifestly impossible for anyone like Pettenkofer who was a scientist of distinction to say what concentration of CO_2 would be necessary to maintain a certain degree of air purity. It is ridiculous on the face of it. Such a thing could not be. The only thing that carbon dioxide ever was used for, as I see it, was to measure the amount of air necessary to remove the objectionable odors in a class room.

Billings, to whom Prof. Winslow referred, is very careful to make this distinction. I have here his 1884 edition, on "Ventilation and Heating." He is discussing the standard of 3000 cu. ft. an hour as proposed by Parks. He says, "As I have stated above when as a product of respiration the proportion of carbonic acid in a room is increased from the normal ratio of between three and four parts in 10,000 to between six and seven parts in 10,000 a faint musty odor is perceptible, assuming that the air of an inhabited room should not be so impure as to *possess this odor*," etc.

And in other places in the book wherever he is referring to the carbon dioxide standard he makes it clear that the standard is a measure of *the odors* in a room and not of the organic impurities. As a matter of fact Parks recommended 50

cu. ft. of air per minute per occupant. Billings himself agrees substantially with this standard. Quoting from p. 41, "I would advise that the heating surface be provided for an air supply of one cubic foot per second per head for rooms which are occupied constantly," or 50 cu. ft. of air a minute.

All of the physiologists were asking for a standard of about 50 cu. ft. of air per min. Meanwhile, the engineer was trying to give it to them. In the first place, Henry Rattan of Canada took the old cockle stove of England, remodeled it into a furnace and introduced it in this country. He started with a very low air supply, about 400 cu. ft. per occupant per hour. He had to heat the air to an excessive temperature on account of using this small quantity of air. The hot air was at the ceiling; the cold air was at the floor. General dissatisfaction resulted. His successors tried to comply with Parks' standard of about 50 cu. ft. of air. Their heating apparatus was not big enough. They couldn't heat the building and also heat this excessive amount of air, and they had to reduce the amount. I believe Mills was from Buffalo. He introduced steam heating in schools, had the same experience until, finally, the engineers and the manufacturers of equipment who were struggling with this problem tried small amounts of air, and failed, large amounts of air, and also failed, finally they arrived at a reasonable quantity which was satisfactory in ventilating a school room. That quantity was 30 cu. ft. per person per min.

Billings asked for 60 cu. ft. originally. All of the physiologists asked for a high quantity but it could not be obtained and Billings finally set the standard in this country in 1888 and he *was sensible*, had sense enough to adopt the standard arrived at *by the engineer* of 30 cu. ft. per pupil per minute. That standard has been in effect from that day to this and I predict it will remain the standard just as long as the specific heat of air is 0.241; so long as the human body gives off 400 B.t.u.'s per minute, because it is an engineering standard that is reasonable from every angle.

Billings' standard which was published in 1880 is one that you ought to know. "In each class room not less than 15 sq. ft. of floor area shall be allotted to each pupil. In each class room the window space should not be less than one-fourth of the floor space and the distance of the desk most remote from the window should not be more than one and one-half times the height of the window from the floor. The height of the class room should never exceed 14 ft. The provisions for ventilation should be such as to provide for each person in the class room not less than 30 cu. ft. of fresh air per minute, which must be introduced and thoroughly distributed without creating unpleasant draughts or causing any two parts of the room to differ in temperatures more than 2 deg. fahr. or the maximum temperature to exceed 70 deg."

30 Cu. Ft. Standard Practical

If you wish to heat a room by the blast system; if you wish to remove the odors or get proper distribution, you would find as an engineering proposition that about 30 cu. ft. is the desirable amount, and this is based on the experience of the engineer and never so far as I can see has it had anything to do with this CO_2 standard.

The CO_2 standard is pretty good today as a measure of air quantity to remove odors. It has been modified slightly in recent years. Fifty years ago we did not have as many bathtubs as we do now. The children were not quite as clean. They probably gave off a little more odor and a little lower CO_2 standard was therefore necessary. We increase it today because the children are cleaner. As a measure of disagreeable or objectionable odors in a room the CO_2 standard is as good as anything we have and that is all it ever was.

The next proposition in Prof. Winslow's paper is that 30 cu. ft. of air per minute is an excessive amount and will create objectionable draughts. Prof. Winslow was kind enough to compliment our work at the Bureau of Mines at Pittsburgh, but our work at the Bureau of Mines has developed a comfort zone through the center of which we have drawn a comfort line and any point on this comfort line represents a combination of temperature and humidity and air motion that is equally comfortable. From our curves it is evident, we can maintain temperatures as high as 75 deg., provided the air motion and the humidity is properly related without any draughts and without any discomfort.

Here is a position you cannot very well straddle. If our work is right and we believe that it is, then Prof. Winslow is wrong, or Prof. Winslow is right and we are wrong.

The third proposition is the one regarding the instance of respiratory disease and I do not speak on this subject with any great amount of confidence because I know Prof. Winslow is so much more capable of discussing it and has much more information than I have or than any of us.

Nevertheless, it is interesting to note that in the entire series of tests conducted by the New York State Commission *there was only one school, according to one of our members,* Mr. McCann, *who was for many years Chief Engineer* for the New York City Board of Education, *in the entire* series where the *mechanical ventilating system was anywhere* near up to *standard,* and that was Public School 97. In the comparison of window ventilation with fan ventilation in Public School 97, both teachers and pupils favor very strongly the mechanically ventilated part of the building. Respiratory diseases were less; the comfort of the pupils and teachers was greater in the mechanically ventilated rooms and it won the contest, if I may use that expression, with flying colors.

Teachers Strike in Window Ventilated School

The only other test I am acquainted with where window ventilation was compared with an efficient fan ventilated school was in the Angell School in Detroit. Here we made very elaborate preparations for tests, using rooms in the same building, some fan ventilated and some window ventilated. We started our test in February some years ago. *After running about six weeks the teachers went on strike and refused to teach in window ventilated rooms,* complaining of colds and troubles of one kind and another and all the tests were discontinued.

Looking at this question in a broad light it seems to me that there should be no distinction made between the *methods* of ventilation provided the *conditions* in the rooms ventilated are carried constant. Mechanical ventilation is I think the method of the future. The keynote of mechanical ventilation is control. With mechanically ventilated rooms nothing is left to chance. With the window ventilated rooms nothing is left *but* chance.

WHY THEATRE VENTILATION IS BETTER THAN LAW REQUIRES

C. L. RILEY: I think it would have been unfortunate if we had had to discuss this question at the time when Prof. Winslow's data were gathered. During the ten years in which he was gathering that data we hadn't as much experience in heating and ventilating as we have had since. He has put the question to us very simply and directly—*gravity window ventilation versus mechanical ventilation*—

and has left the question with a very clear line of demarcation to separate the one from the other.

At the time when the data of the New York State Commission report were gathered commercial buildings such as factories and places where people work were usually heated by direct radiation and depended on window ventilation when they got ventilation. If that practice had been desirable, it would have continued because there was no law compelling the ventilation of factories by mechanical means at that time, nor has there been since in general, only in particular cases. As a matter of fact, we who deal in heating systems know that the best practice in factory design at the present time calls for mechanical ventilation. Not only does it call for mechanical ventilation but it calls for mechanical ventilation in as great an amount or greater amount than is customary or required by law in school buildings. Not only is this true in factories but in the moving picture theatre which is more analogous to a schoolroom than the factory is. The moving picture theatre not only complies with the law in that respect but goes farther than the law requires that we go in school buildings. Why does it do this? It does this because it finds that people will pay good money at the door to go into an auditorium that is adequately and completely ventilated. They prefer to sit there. We find that this is no sentimental matter. It is a matter that can be converted into dollars and cents by the proprietor. That is the kind of practical experience that we are getting every day and such experience as that is the best answer to any claim that mechanical ventilation is not needed.

I shall not touch on the theoretical side of it. Eminent specialists have treated that already, but I just want to point out that since the time when that report was written and the present day the tendency and experience and development of the art has been toward more ventilation and not less ventilation.

RESEARCH WILL REVEAL BEST SYSTEM

DR. R. R. SAYERS: I certainly have enjoyed Dr. Winslow's paper and the discussion. I have known Prof. Winslow and his work for quite some time and I know he wants to do the best thing for the people. I also have been associated with this Society for a number of years and I know that they have the same attitude. Prof. Winslow has called your attention to one method of getting together. He invited you to appoint a committee to meet with one from the association of which he is president, the *American Public Health Association.*

I would like to emphasize the point to which Dr. Hill called attention, that is, that before we repeal laws let's have a standard that is definite. Prof. Winslow is fully cognizant of the fact that he hasn't given all the conditions that may be necessary. He has mentioned temperatures with a moderate humidity only. We should have a little more in it than that. We have found in our experimental work in Pittsburgh that the known factors in ventilation must be definitely controlled. The exact method of control may vary with the conditions to be met. If the two Societies appoint committees to meet and work out from the information at hand the necessary conditions, they may find in some cases that window ventilation is the thing and they will certainly recommend it; if mechanical ventilation should be used, they will recommend that; or, if a combination should prove advisable, it certainly will be selected. I know that mechanical ventilation can be controlled to give any condition desired. It has been done for a number of years in some places.

WASHED AIR BEST HEALTH INSURANCE

EDWIN S. HALLETT (WRITTEN): All discussion in this Society should have but one object—that of arriving at the truth. The viewpoint of the biologist and physician are not identical with that of the physicist and engineer, yet the problem in hand includes both and requires the training and experience of both to reach the solution. The principal difficulty lies in finding common facts and acceptable research methods upon which to erect the structure, the correct system of ventilation of schools.

It is unfortunate that the physician and the organization of public health officers should follow so closely the methods and ethics of the legal fraternity. I refer to the practice of resting official opinions upon "authority" of some place, some time. Such practice is deplored in law, but it is far worse in a scientific subject since the equipment of both men and laboratory are changing so fast that few pronouncements can be secure for a long period. Even Newton and Einstein are questioned by men in the front line of research of today. It is not sufficient to rest behind a quotation of one or more decades past. It has actually been said of the new science of heating and ventilation that it has made more progress within the past seven years than in a hundred years prior to that time. If that be true this discussion should clearly indicate it.

Prof. Winslow is attacking first—the general legal requirements in many states making 30 cu. ft. of air per minute per person mandatory in school buildings. The writer has often stated in these meetings that there is no basis for setting the figure at 30 cu ft. It indicates a total lack of chemical knowledge to use the rise of carbon dioxide as an indication of poor ventilation. Engineers have long been in accord with the statement that the increase of carbon dioxide and the loss of oxygen in the air have no appreciable effect upon its value for respiration. The Professor is too credulous when he accepts the statement that no morbidic exhalation come from the lungs. The fact that a great Scientist has not found such does not in any manner prove that they do not exist. Scientific processes are not sufficiently refined as to weigh odors, and odors certainly do pass from the circulation to the air through the lungs. A very wide band of low concentration of gases is beyond detection by present methods. A concentration of one part of a poisonous gas in a hundred million of air would defy the chemists yet it is well known that one part of ozone in a hundred million parts of air has a very decided effect upon the individual. The one part is measured, of course, before the dilution takes place.

If it were granted that the exhalations from normal healthy children were harmless, the school does not exist that contains only such healthy children. Every healthy child has the right to the protection that ventilation affords him.

If it were further granted that the normal exhalations of all classes of children were harmless, there is sprayed about the room the secretion from mucous in coughing and sneezing and the home contact on the clothing. Every child is also entitled to all this protection that can be had from the ventilation of the room and wardrobe. Ventilation is both mechanical and chemical in its action upon the pupil.

The laws are in error in specifying exactly 30 cu. ft. of air per minute but air motion is the important thing to be secured and it requires volume to produce motion. The quantity per person is not important so long as it does not produce discomfort to him. With the old style of diffuser some care was necessary to prevent drafts but with the present outlet a draft is impossible. The most perfectly ventilated schools to my knowledge are using from 20 to 30 cu. ft. per minute during the heating season.

Another most important function of ventilation which the Professor ignores is the removal of the products of combustion of coal, oil and gasoline of the larger city. The soft coal which is almost exclusively used for all fuel purposes contains 3 per cent and often 5 per cent of sulphur in combination. The sulphur dioxide is present in the City atmosphere in relatively large quantities, so large in fact that the great Botanical Gardens have been compelled to move their propagating lands 40 miles from the city. Sulphur dioxide is an even worse poison to persons than to plants. This signifies that our children are being injured in a greater degree than the garden plants but the cause of the injury is not so easily placed.

The automobile and truck including busses are burning many car loads of gasoline per day in every large city. The percentage of carbon monoxide is high in the exhaust. It is deadly but insidious poison. Its worst effect is not in producing unconsciousness in complete asphyxiation but in filling the hemoglobin with the CO thereby preventing the use of oxygen for aeration. These two active poisons in the outdoor air, that we used to call fresh air, have greatly increased in a few years and most certainly are responsible for great damage to the health of our population.

The new mechanical ventilation not only washes these poisons out of the air but returns the once purified air to be repurified and reused. Many tests have been made to determine the advantage of repurifying the air once used in returning it to the washer and no doubt now exists as to the advantage of so doing.

Nothing but a complete modern mechanical system of ventilation including air washers with humidity control and ozone can accomplish these results. Without, ozone odors do become serious even in the best fan systems, and worse of course, in certain sections of the city, where bathrooms are unknown. Some one has referred to ozone as a chemical, yet the city air contains at least two poisonous chemicals, in larger quantities than those in which the ozone are used.

The fan system if used for no other purpose than producing air motion and distribution would be justified and necessary in view of all the data gathered at the Pittsburgh Research Laboratory. It is admitted that in auditoriums and rooms holding more than fifty persons the fan is necessary but it is not shown why the line is drawn at 50. Can not the individuals of the fifty suffer as much as the individuals of the 500? Of the five points of marking of the official synthetic air chart not one of them can be maintained within permissible limits without a fan. If a difficult situation requires a fan does it not follow that all situations would be better with the fan control?

Professor Winslow's advocacy of open window ventilation of schools has overshadowed in the public mind, all other statements he has made. School officials generally do not get all the facts about the New York Commission, the experiments of which are the basis for the open window contention. They do not generally know that not a modern or satisfactory mechanical ventilating system was used in these tests. They do not know that the commission says that if such a plant had been used the results would probably have been different. The common expression heard is that open window ventilation was recommended.

There are two criticisms made against the fan: That it produces too high temperature and that it causes drafts. These statements seem so absurd to the engineer that a reply is scarcely justified except that it is continually reiterated. The temperature of the air from any modern fan system is controlled by thermostats that are more sensitive than any person and are far more reliable than any humanly supervised control. If 68 deg. temperature is desired the air temperature in a

modern school room will not vary a degree from that from month to month. The high temperatures are always caused by the teacher. All hand controlled radiators overheat the rooms. The teacher cannot be trusted to look after temperature control. Any teacher who lives in an apartment heated to 80 deg. will naturally be dissatisfied with 68 deg. in the school room, yet it must be kept down to that for the protection of the children.

It would seem inconsistent to complain of a draft from a fan moving warm air at a velocity of 200 ft. a minute and at the same time recommend open windows through which zero air is blowing at the rate of 1200 ft. a minute! The truth of the matter is that on zero temperature days and all other cold days the windows are shut tight.

The experience of the writer with the window board ventilation in a number of St. Louis schools not yet equipped with ventilation, is that they are foul smelling and unevenly heated. The attendance records show a much larger absentee percentage than in the mechanically ventilated schools in the same district. It is most certainly true in St. Louis, and there is no reason why it should not be universally true, that the health of the children in a school having an abundant supply of air, conditioned and distributed to the school rooms as a pleasing breath from the seashore, is better than that in which all the ventilation is the air and dirt that is swept in from a filthy alley, not warmed, and uncontrolled. If our food and drink were exposed to the contamination of an open window, we would refuse them; yet the respiratory system is far more vital and subject to serious ills than the digestive. We have been prudent in legislation to protect our food and water supply, yet the doctor would destroy what has been attempted in legislation to conserve the health from respiratory hazards and revert to methods of 50 years ago.

Had we a tropical island upon which to build every school and means of bringing the children home at night, we could then enjoy the open window ventilation; but, as that is impossible, an alternative affords every advantage and produces every result that such an ideal might have. That is the new mechanical ventilation of this day which reproduces every quality of the delightful outdoors in every school. Shall we go forward or backward? Shall we protect our children from the poisons, soot, dust, industrial odors, and other by-products, or shall we open the windows, close our eyes and trust the good graces of the stars to save us?

It is my opinion, based upon a wide acquaintance and as an active member of the *National Association of Public School Officials*, that the recommendation of window ventilation by the New York Commission and, especially, the widespread publication and reiteration of the recommendation, has done more injury to the health and comfort of the school children of our land than all the constructive work in hygiene. Professor Winslow may ever be able to do to counteract it. This is especially true in the smaller cities that have no membership in this society and have no means of knowing the truth. School Officials are not technical men as a rule and see only the headlines of the newspapers, that open window ventilation is recommended as best and cheapest. They are obliged for many reasons to accept every promise of lower cost and they do not know that the open window is far more expensive than the most perfect fan system of complete air conditioning. The cost of construction of such fan system is somewhat less than the cost of a direct radiator and exhaust duct system as recommended, but the cost of fuel to operate the fan, air washer, heat regulation, humidity control, ducts, diffusers, ozone, power plant and auxiliaries is not more than one third of that for the open window system. The writer has data on the fuel consumption of recently built schools in St. Louis in which the annual fuel cost per pupil is as low as 40 cents per pupil or with 1300 pupils in a million cubic foot building the cost of fuel per year per 1000 cubic feet is 52 cents.

It is impossible to heat with steam radiators under the windows in this climate, without opening windows, at that low cost. Official records of costs in St. Louis for school buildings erected within the past 5 years, and equipped with the highest class fans, steel power boiler, air washers, heat control in every room, humidity control, ozone, draft proof diffusers, with no room occupied by radiators, are found to be $27.00 per pupil. To obtain such low prices on a plain radiator system, it is necessary to resort to the cheapest and smallest possible units. If, therefore, the open window ventilation was recommended as an economic measure, that fallacy has been demonstrated beyond all doubt.

The AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS was organized for the purpose of ascertaining and publishing the truth on matters in this field of activity. It has a duty to the public and must speak in unequivocal terms on attacks of this nature or immediately pass off the stage. School officials want to know the truth and we cannot evade the issue nor give a colorless answer. It is not a matter of personalities nor ethics. It is not involved in local customs and practices, nor is it affected by the past failures of poor apparatus and untrained operators. The public wants to know what is the merit of mechanical ventilation when built and operated by those who know its value and not by those who for long periods have tried to discredit it. Any one can easily know how bad open window ventilation is, but it is a matter of very special skill to construct a mechanical system that shall rival natures cleanest and best outdoors. The writer would close this discussion with the statement of an incident that may assist in appreciating the value of good ventilation. On an inspection visit some three years ago to the Rose Fanning School, the writer noticed a teacher surrounded by a class of third or fourth year children. He said to her, "How is your new ventilation working?" Said she, "What do you mean? I didn't know of anything new." Then a brief explanation of improvements in summer repairs followed. "Now, maybe that explains something that has happened to these children. When school began in September a number of these children were pale and thin and now you see how rosy-cheeked and fine they are. I have noticed this unusual condition and have spoken to several about it. I was unable to account for it, but now I understand."

With incidents like this occurring now and again, it heartens the engineer to know that the 120,000 children are receiving the best care and protection that their officers can secure for them.

HOW CAN TEMPERATURE AND DRAFTS BE CONTROLLED?

PROF. A. C. WILLARD (WRITTEN DISCUSSION BY V. S. DAY): I have the following points to offer in the discussion of Prof. Winslow's paper:

(1) If in schoolroom heating the thermometer on the teacher's desk is to be used as the index and maintained at 68 deg., it would be desirable to know what would be the temperature around the feet, and in fact entirely surrounding the desks of the pupils in the lower grades. My own impressions, based on observations made at the University of Illinois, are that the temperature at the points mentioned would be too low for the comfort of the pupils.

(2) Proper control of window ventilation is a difficult matter and may not in my opinion be expected of a teacher even though her efficiency as a teacher be dependent on the exactness with which she observes such classroom details. This is, of course, a matter in which the opinion of the pedagogue and school superintendent is worth much more than mine, but it has also been my observation that

most women are not careful observers of temperature conditions in rooms and usually allow the temperature to go to extremes before making adjustments.

(3) Although admitting that humidity is a factor in the determination of correct comfort conditions the paper does not mention any means by which humidity can be controlled with the window ventilation.

WINDOW-METHOD INEFFECTIVE IN SUMMER

DR. C. W. BRABBÉE: I think I can give you a little information, first, about the Pettenkofer CO_2 method. Pettenkofer used CO_2 not as a poison, but as an indicator for other unmeasurable products as odors, toxines, etc. Besides his CO_2 method there was developed a method of humidity and a method of overheating the room and since 1915 this latter method of overheating the rooms replaced the CO_2 method.

In Charlottenburg I had a lecture room in which I began with 50 pupils but very soon this figure increased to 200. In this lecture room I introduced air at 50 deg. fahr., with 10 times air change and not one complained of draught. Then I was asked to make such a system in this country and I did. We introduced in summer time, a lot of cold air and also made provision to heat the air. I was fearful that the people might be rather sensitive and I did not want to be blamed, but we never used this heating device. We always introduced the cold air. It was very popular in offices.

One question which was not touched on today is ventilation in summer. We have some schools which run during the summer. What about the ventilation in those schools? Finally a last remark we were told in the building, "If you are going to introduce this ventilating system you will have an awful job to get the people to keep their windows closed." When we started this system I went to that office and said, "Ladies and gentlemen, we are installing a ventilating fan system. Please do not open your windows." The Superintendent told me there was no use; that they would open them anyway; however, they didn't. They found the ventilating system so good that they did not want to disturb it.

CONTROL IS THE VITAL THING

C. A. BULKELEY: It has been some years since I have been connected with schoolhouse ventilation, but I was for four years connected with it in St. Louis; so, although it is sometime ago, I remember some things. I would like to ask if the answer to window ventilation isn't found in this one thing—control. Will you tell me how you are going to control the quantity of air that comes in through an open window when you have a breeze in one direction say of 20 miles an hour which exercises a static pressure of perhaps $^1/_8$ of an inch of water with perhaps as much negative on the other side of the building; and you have a velocity under the window of 1200 ft. a minute one day or one hour and perhaps you find the air dragging out of the window the next day or hour?

It is granted that you have to have some form of fresh air introduction into a room where human beings live. Prof. Winslow condemned the fan system because it furnished too much air. If it did, why didn't he run it at half speed? Mechanical ventilation systems do not have to introduce 30 cu. ft. of air by any means. It can introduce 5 or 10 or 20, and if 30 is too much, then put in what

is required, but by all means control it so that you can get some kind of results that our doctors tell us our children need.

HASTY CONCLUSIONS MADE FROM VARIABLE DATA

A. R. ACHESON (WRITTEN): When the report of the New York State Commission on Ventilation was issued, I read it and was struck by the frequency with which conclusions were not properly supported by the data submitted or were drawn without sufficient data being available. I marvelled that the authors could put their names to the report when they were aware that the divergences of the test data were so very great. In my judgment, these variations were often so great that they swamped the difference which the experimenters were trying to ascertain.

The report is divided into two main parts, Part I, describing tests made in an observation at the College of the City of New York, and Part II, describing tests made in various schools, chiefly in New York City.

The observation room was 14 ft. by 10 ft. by 10 ft. and data were obtained covering the effects of various air conditions on various groups of students, four at a time. Naturally it is very difficult in such an experiment to maintain all conditions constant except the one whose effect is being determined. I am not surprised at the variations but I am surprised that the authors should draw definite conclusions from such variable data. For example: when testing the difference between the effect of air at 75 deg. and 68 deg., the temperature, when 75 deg. was supposed to be maintained, would frequently vary from 70 deg. to 82 deg. In one series of tests, July 6–10, 1914 (page 31) the overall variation was never less than 7 deg. and in one test there was a variation from 67½ deg. to 84 deg. All these varying tests were averaged and conclusions drawn from the supposed effects of a sustained temperature of 75 deg. fahr. Similar averages were obtained from widely varying data for temperatures of 68 deg. and 86 deg.

The summary of one test to determine the relation between controlled atmospheric conditions and body temperature (rectal) Table 3, p. 52, series VIII–75p.) the body temperature of the students was as follows:

9.00 A.M.—98.55, 12.00 M—98.35, 1.00 P.M.—98.31, 4.00 P.M.—98.58.

The authors record this as an increase of body temperature of 0.03 deg. fahr. I presume that if they had stopped the experiment at 1.00 P.M. it would have been recorded as a loss of 0.24 deg. fahr. The report does refer to the diurnal change of body temperature but did not include it in the summary of Table 3.

It is a usual procedure, in engineering work at least, to measure changes over the complete cycle and if in an experiment the temperature should fall and then rise the engineer would usually continue the test and find out the real cycle and would not be content to take a portion of the cycle. In the experiment recorded the conditions were supposedly constant from 9 o'clock on, but yet the body temperature dropped 0.24 deg. fahr. and then rose 0.27 deg. fahr. from the low point. It would seem to be the duty of the experimenter to take such a variation thoroughly into account before drawing hasty conclusions as to the effect of atmospheric temperature on the rectal temperature. It would seem to the writer that more than one condition was being changed and that the test results were not conclusive and that further experimentation is needed along this line. Personally, it would seem that there should be some record as to the physical condition of the subject

and when changes of body temperature are being considered it is essential to know the starting conditions as well as stopping conditions.

In an engineering experiment to determine the efficiency of a boiler furnace and grate, the test is made to include a complete cycle including firing and cleaning periods. This phase of testing was not properly safe guarded in the tests under consideration. Table 3, page 52, gives the rectal temperature after exposures to air of different temperatures as follows:

68 deg. 50 per cent relative humidity—98.11 deg. fahr. rectal temperature
75 deg. 50 per cent relative humidity—98.53 deg. fahr. rectal temperature
86 deg. 80 per cent relative humidity—99.34 deg. fahr. rectal temperature

On August 15, 1914 (series V) the average rectal temperature of students on arrival at the observation room at 8.00 A.M. was 99.55 based on eight readings. Are we to conclude, therefore, that these subjects were more affected in a harmful way by the conditions prevailing at that time than they were after exposure for $7^1/_2$ hrs. to a temperature of 86 deg. and 80 per cent relative humidity? One of my points is that the authors have nowhere given any evidence that a change of rectal temperature from 98.11 to 98.53 is harmful. The authors of the report consider that Fig. 22, page 58, shows a marked similarity between the rectal temperature of the body at 8.00 A.M. and the mean outdoor temperature of the previous period from 9.00 P.M. to 8.00 A.M. Even a cursory examination of the curves shows that the variations swamp the differences and the conclusions, as based on these data are unjustified.

Fig. 21, page 57, shows that on June 12, the body temperature of the subjects taken at 8.00 A.M. was 99.45 which is higher than the 99.34 given as the final temperature after exposure to 86 deg. fahr. and 80 per cent relative humidity. If the small difference in rectal temperatures recorded in Table 3, are really important are we to infer that the subjects, whose temperatures were recorded at 8.00 A.M. on June 12, were really suffering from the effects of overheating?

A baffling feature of the report is the frequency with which the authors admit the lack of evidence or wide variations in evidence and then promptly draw the definite conclusion with great emphasis. For instance on page 196, they state "at 75 deg. fahr. the rectal temperature changed but slightly;" but on page 199 they state "We have found that even slight overheating at 75 deg. fahr. produces the following harmful effects—(1) A burden upon the heat regulating system of the body leading to an increased body temperature, etc." This is a good example of blowing cold and blowing hot.

The authors admit that a temperature of 75 deg. has but a slight effect on rectal temperature and some other physiological conditions but yet claim that the supposed effects found in the school tests were largely due to the difference of 2 deg. fahr. in the average room temperatures for window and fan ventilated systems (difference between 67 deg. fahr. and 69 deg. fahr.). I am heartily in accord with the authors in emphasizing the effect of temperature. I believe temperature to be a primary factor in ventilation, but if I had no other evidence than that submitted by these tests I should not be so sure of the accuracy of the opinion. In other words the variableness of the data leaves me without much confidence in the conclusions to be drawn from them. On page 196, the report shows the variation of heart rate as follows:

Temp. deg.	68	75	86
Per cent relative humidity	50	50	80
Heart Rate	66	81	74

and states "at 86 deg. and 80 per cent relative humidity the heart rate rose"—a fairer statement would be that, as far as the recorded data go, the heart rate rose at 86 deg. fahr. and 80 per cent relative humidity as compared with 68 deg. fahr and 50 per cent relative humidity, but fell as compared with 75 deg. fahr. and 50 per cent relative humidity.—In other words take your choice or admit that the change in relative humidity caused the difference, or perhaps fairer yet—say the data are too variable, let us refrain from drawing a definite conclusion.

On page 199, of the report the authors claim that even slight overheating at 75 deg. fahr. produces the following harmful effect—

> a markedly abnormal reaction of the mucous membrane of the nose leading ultimately to chronic atrophic rhinitis, and when followed by chill, producing a moist and distended conditions of the membranes calculated to favor bacterial invasion. In animals, exposure to high atmospheric temperatures, particularly when followed by chill, diminishes the protective power of the blood and markedly increases general susceptibility to microbic disease.

The strange thing is that not one of the tests recorded in the report on this particular investigation was made at 75 deg. and so the conclusions are drawn from the air, so to speak. In a similar manner an engineer can go through the whole report and demonstrate that the conclusions are drawn too hastily from widely varying data.

Several places in the report the authors concede the viewpoint held by engineers on ventilation is justified and then will promptly forget this and concentrate on their enthusiasm for the effect of temperature alone.

The following is a quotation from the report, page 199.

> Our results in regard to the influence of the chemical composition of vitiated air (temperature and humidity effects being excluded) have been generally negative. In two respects, however, our experiments suggest that some chemical constituents of the air of an unventilated room may be objectionable. Such air appears (1) to decrease the appetite of human subjects for food and (2) to diminish substantially the amount of physical work performed under conditions of equivalent stimulation.
>
> We may conclude then that the primary condition of good ventilation is the maintenance of a room temperature of 20 deg. Centigrade (68 deg. fahr.) or below without the production of chilling drafts; but that it is also important, on account of certain subtle but real effects of vitiated air upon appetite and inclination to work, to provide for an air change sufficient to avoid a heavy concentration of effluvia such as was associated in our experiments with a carbon dioxide content of 23 to 66 parts per 10,000 cu. ft.

The above might easily have been stated by any of the well known practicing heating and ventilating engineers. (See Appendix A.)

Time does not permit my commenting on the second part of the report in detail. Sufficient to say that in my opinion the tests in the schools do not justify the conclusions drawn by the authors. The supposed results on the respiratory condition of the students were not due to the type of ventilation—the variations were too great to justify that conclusion. The results are self contradictory and it is unscientific to add items that do not correspond and draw a conclusion from a mass of heterogeneous averages. Merely calculating the probable error does not condone this unpardonable sin.

The authors recognized this principle and then promptly forgot to use it. See page 437 where they say "Incidently this illustrates how an erroneous impression may be gained from the averages alone." That is the trouble with the whole report and that is why personally I take the position that the results of the report are largely negative and call attention to the fact that further scientific tests are

required to demonstrate the effect of various atmospheric conditions on comfort and health.

I must reserve comment on the general question of window versus mechanical ventilation to a later date.

It is interesting to point out that the report of the New York State Commission on Ventilation states on page 451 "Fan ventilation in school buildings as a principle is not to be condemned from the results of this investigation."

Appendix A

As far as I can see, the engineers and doctors are agreed on the general requirements for good ventilation, but differ somewhat on the importance of each phase of the question.

Engineers and doctors are evidently far apart as to the best means for getting the results desired. It would seem to me that in general the health officers are the best fitted to state the general requirements for good ventilation, based on scientific tests, and that the engineers are the best prepared to provide the best equipment. The work of either group should stand careful reviewing, as to the results obtained, by the other group.

LIKES OUR HEATING, FINDS VENTILATION FAULTY

DR. FRANCIS E. FRONCZAK: When a man of the reputation of Dr. Winslow has been treated the way he has been I hate to think what will be done to me. For 25 years I have devoted my life to preventive medicine. For 20 years I have been Health Commissioner of Buffalo and am somewhat interested in this subject. There is no doubt that the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS has done much in the standardizing of heating and ventilation practice. This afternoon I see they are fighting for their very existence and fighting hard. I never saw any society or any profession fight as hard as your Society has fought, and although you appear quite active, I am afraid you are going to die as ventilating engineers unless you provide something better than you have done heretofore.

Fool-Proof System Wanted

As Health Commissioner of the city I have taken up the study of ventilation of schools, both here and abroad. I have heard a good deal about the various kinds of mechanical systems, and each system was supposed to be the best. I suppose if someone could devise a fool-proof mechanical system it might be all right, but it has not been found as yet. In our schools in the city of Buffalo where we have spent hundreds of thousands of dollars for mechanical ventilation, what do we find? In some instances the inlets and outlets covered with newspapers and with rags. The fans placed either at the street level, so the dust from the street will be sucked in and sent to the rooms, or we find them placed in the attic and all the smoke from the neighboring factories sent to the rooms. In other words, whatever was undesirable found its way out into the class room. I remember a school placed in the stockyards district next to a slaughter house and they got everything in the rooms including the squeals of the pigs as they were slaughtered. And yet the municipalities spend thousands of dollars for mechanical ventilating systems.

We found that almost invariably the fault of the mechanical system was that

it was run in every way except the one recommended. Again I repeat, if somebody can find a fool-proof system, he will really be a great inventor. I do hope there is such a man among you in this Society.

A gentleman spoke of the school in Charlottenburg. In 1910 I saw the open-air school in Grunwald near Berlin, Germany. I would favor such a school. In fact, I believe the time is coming when the average auditorium, hall or school will have only three walls, the fourth wall will be open to the outside air.

Open Air System Favored

I want to place myself on record that so far as Buffalo is concerned, and most of the schools of the country are concerned, for I have visited quite a number of cities to study the subject, at the present time we are for open-air ventilation, not because I like it, but it is the lesser of the two evils.

I believe that so far you have been headed in the wrong direction. Not everybody discovered America the first time he tried. Columbus showed us the way. A lot of people endeavored to determine the origin of tuberculosis before Koch. Koch found it but he was not the last word on the subject. A lot of men came after him who improved his methods and his discoveries. The same thing is true in every invention. You are trying to do something and you are doing your level best, but there is a whole lot yet to be done.

Ventilation of a room depends largely on three things. No person is going to feel very comfortable if the temperature is 72 or 75 or 80, which we sometimes find with the various systems of present-day ventilation. A good deal depends on the humidity. When you have a room that is as humid as a laundry on Monday and smelling like the stockyards, the humidity running about 80, you are not going to feel comfortable no matter what system of ventilation you may use. The third point to be taken into consideration is the mobility of the air. Stagnant air, no matter what you do, will never be good air.

I want to compliment the Society on what they are doing in the way of heating. They have really done a good deal. They have really improved the methods of maintaining suitable uniform temperature regardless of outside air. Not so many years ago I remember a fellow would stand with his back to the stove, would be half roasted on one side and frozen on the opposite. You have improved that. I believe the American Institute of Thermal Research has done a good deal. I have followed their work and I believe they have done a good job in the line of thermal research. I believe the other half of your Society, the ventilating part is certainly trying to do something, but as a matter of fact they are groping in the dark with their eyes blindfolded. You may perhaps accomplish something that way, but I am afraid you will not. Keep on working and in time you may discover something that may be worthwhile, but as yet, with due respect to you as guests of this municipality and I as a part host, you are far from attaining what we are after.

Mechanical ventilation, no matter what system may be introduced, no matter how much money you have spent, no matter who is backing the system, if it is operated in the way it is at the present time, with inlets and outlets closed with newspapers and rags, with the fan placed next to factory chimneys or slaughter houses, or at the level of the street, with janitors so many times forgetting to turn off the fan when he goes to sleep at night, as often happens, again somebody suddenly calls attention to the fact that the fan has been closed for several days; something is wrong. In any system you require the human element which is necessary for its

successful operation, but there should be uniform control of the equipment. Keep on working and I believe in due time you will discover something which we hygienists will be proud to make use of, but so far you haven't been entirely successful.

WORLD DEMANDS A SCIENTIFIC VENTILATION STANDARD

F. PAUL ANDERSON: Mr. President, this meeting is getting rough. Yes, sir, my dear friend, you are right when you say we are looking for fool-proof ventilating apparatus. We are also looking for fool-proof tires, fool-proof automobiles, fool-proof window ventilation, and even for fool-proof sweethearts. To be surrounded with fool-proof everything would be heaven itself.

I think it is unnecessary to reply in any great detail to the last speaker because he has merely a rambling, erratic talk, clearly indicating that he knows nothing of serious moment about the subject of ventilation. I would say that he is more interested in the politics of the situation than in creating scientific methods of logical ventilation for the benefit of mankind. The point that the last speaker makes about mechanical systems not operating is, of course, sometimes true. This condition of affairs is merely a reflection upon those responsible for the control of the material elements in connection with public buildings. Something must be done to make boards of education more alive to their responsibilities in this direction. It would be well to introduce some engineering elements into the governing boards of our schools to see that mechanical ventilation plants are properly designed, properly installed and effectively operated. The fact that we have some poorly-operated ventilation plants is no excuse for the plea that we discard this type of ventilation and go back to the cave man processes of bringing fresh air into our crowded rooms.

I desire to say to the last speaker that if he thinks the engineer is dying hard he was never more mistaken in his life. There never was a more optimistic set of men on the face of the earth than engineers. "In the lexicon" of the engineer, "there is no such word as fail." You may be sure that we engineers will resent the insult that we are dying hard. I assure you that we are not dying hard, and have no feeling in our hearts that we have been defeated, but we are going to put a stop to the unfair tactics and wholesale feeding to the non-technical public this indigestible and undigested information relative to effective methods of ventilation for public schools.

Science Is Progressive

Now to a discussion of the formal paper presented by our distinguished friend and visitor, Prof. C.-E. A. Winslow. He has certainly thrown down the gauntlet to the ventilating engineer. I was very much interested in his statement that we must have mutual and cordial relations in the discussion of matters of this sort. I concur in the tribute he paid to the *American Public Health Association*. It is indeed a great body of men; one of the most potent and influential organizations in America, especially pertaining to that most precious of human possessions—health. I comprehend his announcement that science is a progressive thing. It is, Professor Winslow, a very progressive as well as a very sacred power. If we stop for a moment to consider the material development that has taken place in America and in the world at large, we must conclude that science has played a real part in the present civilization. Science is responsible for practically everything

today contributing to our comfort, our health and our intelligence. We are under eternal obligations to scientists.

For centuries the seas were traversed by the old sailing vessel. There is nothing so fascinating in all of the human experiences of the past as the romances and tragedies of the sea. Human beings and the commodities of nations were transported solely by barks carrying sails. When the steam-propelled vessel was proposed, it was predicted that it would be impossible ever to make a steam-propelled craft that would be able to carry enough coal to propel itself across the ocean. The way this myth was exploded is known to all of us. In the days of the old sailing vessel there was no certainty of movement across the deep. Man was subject to the whims and uncertainties of the wind. *This crude theory of window ventilation occupies the same relation to modern methods of mechanical ventilation that the old sailing vessel bears to the superb modern trans-Atlantic liner.*

I can remember, and many of you present can recall, when the greatest possible opposition was offered to the innovation of steam heating, and there was a universal protest to the idea of doing away with the old cannon stove for heating assembly halls. The cry became almost a wail: Why spend so much money to put in pipes and boilers when we can use the old cannon stove to heat so satisfactorily and economically our school houses? Mr. Warren Webster, one of the pioneers of efficient steam heating, who is present at this meeting, can remember the opposition to the introduction of steam heating. Now no one questions the value and importance of heating by steam. Every building of any size is now heated by steam, hot water, or warm air supplied by furnaces. The general public has long known that the engineer is sure to heat all classes of buildings in an intelligent and definite way.

Cannot Ignore Progress

The only difference that I have with Professor Winslow is that he is ignoring the progress that has been made in the science of ventilation and gone back to a process as crude as that employed by the old sailing vessel. I do not want to be personal, but, gentlemen, here is a great issue at stake affecting the welfare of humanity. The scientist and his work is maligned frequently by somebody. There appeared in America two decades ago William Jennings Bryan, who had the effrontery to deny evolution in all of its relationships. He would liked to have seen the unthinking masses adopt a program looking to the destruction of all of our modern scientific thought. Bryan had a tremendous following. In fact, no man has ever been closer to the hearts of the American people than William Jennings Bryan. He spoiled his chances for an immortal place in the world's history by clinging to a fool doctrine contrary to human intelligence, knowledge and experience. Bryan would never listen to scientific truths, he always was hitched up with some hysteria like 16 to 1 or fundamentalism. Intellectual progress played no part in his career. The anti-evolution propaganda was spread generally over this country. The Tennessee episode is well-known. There was an attempt to pass an anti-evolution bill by the Legislature of Kentucky now in session but the movement failed. A Kentucky wag, member of the Legislature, introduced the following resolution absurdity:

> In consideration of the fact that there has been introduced in this house a bill to prohibit the teaching of certain scientific principles in the public schools of Kentucky, it is the sense of this house, the Senate concurring, that other natural phenomena, even more embarrassing to Kentuckians than the theory of evolution, should be properly

regulated by the present general assembly, for the good of all Kentuckians, and for the further purpose of properly safeguarding and protecting our ignorance.

Therefore, be it resolved, by the House of Representatives, the Senate concurring, that, by the power this general assembly is wont to assume, it is herewith deemed advisable to change other natural laws also. The solar system is hereby declared to be grossly inefficient. It is a fact, known to all, that the sun furnishes too much heat in summer, and not enough in winter. The present general assembly takes pleasure in correcting this matter, by ordering the orbit of the earth so changed that Kentucky will enjoy an even temperature of 70 deg. fahr. throughout the year. This general assembly will also order the North Star to quit loafing and from this time forth to follow the orbit of the earth.

Be it further resolved, by the House of Representatives, the Senate concurring, that henceforth water shall run uphill. This improvement on the natural laws will make Kentucky first among power-producing states of the world.

Be it further resolved, by the House of Representatives, the Senate concurring, that scientific agriculture shall no longer be taught in the public schools of Kentucky, for the reason that the science of agriculture is both founded and based on the theory of evolution, so brilliantly demonstrated by Luther Burbank.

Be it further resolved, by the House of Representatives, the Senate concurring, that scrub sires be no longer discouraged, both in and out of the general assembly.

A very interesting parallel can be drawn between William Jennings Bryan's anti-evolution hysteria and Prof. C.-E. A. Winslow's advocacy of window ventilation. The thinking world will not any more accept this unscientific and unwarranted ventilation standard than it will anti-evolution propaganda.

Not a Scientific Document

A very generally accepted impression that open-window ventilation was proven to be the most effective by the studies of the New York State Commission on Ventilation is abroad in the land. It is difficult to understand how such an impression should be gotten from the report itself for this report of the New York State Commission on Ventilation does not prove anything. The open-window ventilation idea has been advanced by Professor Winslow and his followers.

The inference that open-window ventilation has a scientific backing is due: *First* to the fact that Professor Winslow was chairman of the New York State Commission on Ventilation, and, *Second,* to the misunderstanding that the report of the New York State Comission on Ventilation is a scientific document. The New York State Commission on Ventilation made many observations but carried on no scientific studies. Physical laws are not determined except under conditions where constants can be established, and the New York State Commission on Ventilation did not in a single instance set up a strictly scientific condition for determining a physical law. There were too many variables always existing when data were collected. The conclusions drawn are unwarranted as there were no strictly scientific data secured upon which to base any accurate conclusion. The entire work of the New York State Commission on Ventilation as recorded in its formal report is of no permanent value because the whole procedure was unscientific.

Health Body Misled

This report will do untold harm because it will tend to slow up progress that was being made very rapidly toward the solution of a rational method of ventilation. What I say today is meant as no personal discourtesy to Professor Winslow but I do, with hundreds of others, resent the fallacious propaganda that has gone forth from one end of the country to the other over and over again. I think

that famous resolution offered before the great and powerful *American Public Health Association* one of the most vicious edicts that was ever announced by a body of intelligent men. It would have been all right, Professor Winslow, to disagree with engineers and seek cooperation, but the *American Public Health Association* had no right to pass on ventilation with so little knowledge at command. Whoever was responsible for putting before that great association this unwarranted and misleading resolution has done untold injury to the progress of ventilation.

It is now necessary for you members of this AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS interested in the evolution of your own science to make the fight against further misrepresentation. You should not sit by idly and have this fallacious propaganda heralded from one end of the country to the other before boards of education and owners of buildings who are honest enough to accept what seems to be the truth about ventilation. The conclusions of the New York State Commission on Ventilation are unwarranted. The program outlined by the New York State Commission on Ventilation was pretentious and commendable but the work was never completed. Money was not available to complete the seven elements of the study. Only three were completed. It was apparently to be a valuable contribution to science in that serious-minded men were trying to find out something. But when conclusions are drawn from that so unscientific and unfinished report that we should now discard all of the intelligent practices of hundreds and hundreds of men backed by physical science, to go back to the primitive idea of simply opening a window in order to get air into a room, then I think it is time for us to protest in a most vigorous fashion.

Truth Will Win

I would much prefer to have discussed the status of ventilation before the *American Public Health Association* than before this body because I realize that I have here a sympathetic audience and one that does not need educating. Every man interested in ventilation must take the time and the energy to stop this program of misconception and misrepresentation. The purpose of this engineering society is to render service to mankind through properly heating and ventilating homes and public buildings. What has this organization already done? It has established a great laboratory at Pittsburgh for the special purpose of trying to find out some truths relative to man's behavior in every conceivable quality of air, and while you are spending all of that money and energy, going along in your modest way, you have something immature broadcasted to the ventilation inquirers that makes any scientific approach unnecessary for "all" has been proven by the New York State Commission on Ventilation.

Then a man named McLure comes along, a graduate student, and makes a book. He spends a lot of time in the shadow of Columbia University. I know students. I have worked with them for thirty-five years and I know what kind of discrimination they possess. McLure learned how to pass on ventilation queries under a reading lamp in a library. He draws as well as copies conclusions fr m the report of the New York State Commission on Ventilation and he sends from his youthful broadcasting station a siren song on the ventilation of school buildings by means of the open window. This book of McLure's is the work of a college boy; but how do boards of education know that? They are lead to a copy of this McLure book, see these ideas presented, and accept them because they were born at Columbia, the fountain head of the pedagogue. It will take you men a long time to overcome the effects of that particular book. If you gentlemen have never read it,

read it, and you will see how far away from the truth a man can get when he sits at the feet of the ignorant and prejudiced. The picture is McLure, not an engineer, but a graduate student compiling something for an advanced degree, trying to tell humanity something authoritatively on a subject he learns about through the medium of unscientific literature.

At the Pittsburgh Research Laboratory facts are not obtained from literature alone, but also from studies involving a great variety of observations on many human beings in environment under perfect control. In fact, under conditions of observation where we know exactly what happens. It is not a haphazard guessing. The New York State Commission on Ventilation report is a question of observation where conditions are variable and not of scientific determination of facts under constant conditions. We sincerely hope, Professor Winslow, that you will see your way clear to help counteract this very great harm that has been done through giving the impression that open window ventilation is all-sufficient. We wish that a committee could be appointed where we could get intelligently into a cooperative frame of mind and solve this ventilation problem. The whole procedure is perfectly clear. Do you think Dr. Sayers and other physiologists can determine what is the most desirable atmosphere for the comfort and health of humans? Do you believe that can be done? We all do. There is not a single man in the medical profession who believes that ideal atmospheric air cannot be determined and defined.

All right, that is one premise. Do you believe; gentlemen, that the engineer can condition any quantity of air so that it will possess in any prescribed degree temperature, humidity, cleanness and movement?

Let the Laws Alone

One of the most undesirable things about this window ventilation is that no method is possible for cleaning the air. It takes power to put air into a building through a resistance like an air washer or air filter. Do you believe we can make air of any quality? After we find out what the ideal air is, can we not condition it to that particular quality? Of course, you believe that. The engineer has used power from the beginning of time. That is the business of the engineer. The art of engineering is the art of organizing and directing men and of controlling the forces and materials of nature for the benefit of the human race. Of course you know you can condition and move air. Then why cannot the engineer in cooperation with the man who tells us the quality of the air produce a perfect ventilation? All this talk pro and con does not amount to much, I take it, because at the present time neither the physiologist nor the engineer have final conclusions relative to ventilation standards; then let the State ventilation laws alone until we do find out. I am only contending, gentlemen, for one thought. That is, that we should all cooperate patiently and consistently and should not announce anything until it has been proven. That is the great weakness with us all in rushing America. We put the public in an uproar too often just to see the excitement and make a personal reputation. The newspapers are just as willing to accept something unique about ventilation as they are anything else that is sensational. It is retrogressive and not progressive and, therefore, we should, doctors and engineers, travel intelligently together in this search after the ideal ventilation of especially our schoolrooms.

I take it that this great Society is one of the benefactors of mankind and I take it that the notable laboratory at Pittsburgh, as I have so often said, is one of the most progressive institutions ever created by any scientific society.

Why quote anything Germany has done, as the last speaker did? It is a notorious fact that there has been very little development on the continent in heating apparatus alone. They know less about ventilating apparatus and air conditioning.

There have been some great pioneers in this heating and ventilating game. I picked up a little book in my library the other day written by William J. Baldwin, aggressive blazer of the heating trail; one of the great pioneers. I think of that man with great reverence because he wrote a book, Steam Heating for Buildings, which was the first technical book I ever read, over forty years ago. Here are two little books by William J. Baldwin, "An Outline of Ventilation and Warming" and the "Ventilation of the School Room." There are many fine bits of wisdom in these little books. I was struck with the frontispiece—a little girl out in the meadow, mountains in the background. The title is "Fresh Air." What an ideal that is for us to strive after. Of course one will admit that if one could live out in the fresh air all of one's life without any heating apparatus, one would be very happy. As a matter of fact, when one opens the window the air does not always come into the room any more than a sailing vessel always goes to India without a stop. We are obliged to depend upon the whims of the winds in window ventilation as well as in sailing. The engineer who understands how to move air mechanically does not pay much attention to the wiles of the winds. He knows the physical laws back of air movement. He is making God's forces and materials do his work systematically and positively. This suggestion that we go back to the open-window ventilation is out of harmony with all the progress man is making in all other directions. The ventilating engineer resents a suggestion so primitive and so unprogressive.

The courage and persistence of the engineer has been expressed in recent conflict between radio and phonograph. The radio comes upon the world like a dream. What happens to the phonograph? It staggers a bit, but nothing ever puts out of business completely any device in which the engineer has faith. What does the phonograph producer do? His attitude is just another illustration of how one scientist's efforts, intelligently and sincerely applied and cooperating with others, all adds to the wealth of engineering achievement. The reincarnated phonograph gave me a greater thrill than anything man-made ever did in all my life. The radio principles have been hitched to the old phonograph and amplification has found real perfection. The phonograph man said, "No, indeed, I will not stand for that great inroad into my business." He develops a phonograph that is to my mind far more marvelous than the radio itself. If any of you have not heard those phonographs just born with the radio amplification principle, hurry, for you must not die without this experience. There has never been anything produced that represents as this phonograph does the determination of one engineer to counterpoise and cooperate the work of other engineers in parallel, competitive and related fields.

The Window Idea Primitive

Professor Winslow, this is all said seriously yet with courtesy of heart. I have no apologies to make. I do not want to take issue with you personally. I am radically opposed to the open-window ventilation you propose. It is out of harmony with a rational progress in ventilation philosophy.

You must admit, Professor Winslow, that we have given to the ventilating engineer a wealth of conclusive findings from the Society's Research Laboratory at Pittsburgh. You pay much appreciated tribute to the achievements of this Laboratory but we are disappointed that you do not take the facts and tie them to

a positive method of moving air. We will some day, prove more definitely just how many air changes are desirable. This amount necessary causes some difference of opinion now. There is one thing quite plain, however; whatever is that number of air changes required window ventilation will not positively and constantly give what we specify. There is another thing quite sure, too: Mechanical movement of air is one of the facts as well known to the engineer as the law of gravitation.

America Wants the Best Ventilation

If I had time to bring before you the array of scientific facts to show how close we have arrived to the atmospheric idealism at the Pittsburgh Laboratory, I would also answer the thought of cost of ventilation systems you stress so much. What would two or three million dollars a year be for new installation of ventilating apparatus, if we contributed to the slightest degree to the health of our boys and girls? In this age of having everything we want, this argument, even if valid, would not scare many boards of education who wanted really to serve the kiddies of this country.

Three million dollars a year for fresh air; one million dollars a week for chewing gum.

The American people will pay for fresh air and the engineer will soon show the way if open-window ventilation propaganda does not succeed any better than Bryanism. Open-window ventilation may travel hand in hand some distance with anti-evolution but truth and science have clasped hands because they are congenial traveling companions.

Clarence Darrow just after the Tennessee fiasco sent me the following poem by that lovable Chicago column writer B. L. T.

When quacks with pill political would dope us,
When politics absorb the livelong day,
I like to think about the star Canopus,
So far, so far away.

Greatest of visioned suns, they say who list 'em!
To weigh it science always must despair,
Its shell would hold our whole dinged solar system,
Nor ever know 'twas there.

When temporary chairmen utter speeches,
And frenzied henchmen howl their battle hymns,
My thoughts float out across the cosmic reaches
To where Canopus swims.

When men are calling names and making faces,
And all the world's ajangle and ajar,
I meditate on interstellar spaces
And smoke a mild seegar.

For after one has had about a week of
The arguments of friends as well as foes,
A star that has no parallax to speak of
Conduces to repose.

Why worry too much over the flaunting of illogical engineering possibilities such as open-window ventilation? Let us go about our business, finding engineering truths and clinging to them, as we "smoke a mild seegar."

COOPERATION WILL BRING THE IDEAL IN VENTILATION

PROF. C.-E. A. WINSLOW: I want to say, first of all, in closing this discussion that I have never spent a more delightful and stimulating afternoon; and to thank you for the frankness and good-humor and good sportsmanship with which our

differences have been thrashed out. The only one of the speakers who really took me by surprise was Dr. Fronczak with his curious mistake about the identity of the corpse. I thought it was I, not the Society, that was "dying hard."

It is perhaps true that I ought to apologize for bringing Pettenkofer so prominently into my discussion and I want to explain that I did it not because I think any of you believe in him today but because I thought, and still think, that the Pettenkofer theory is the historical basis for the 30 cu. ft. constant. I think if you look at any of the text books on hygiene or on ventilation you will find the 30 cu. ft. standard deduced directly from the carbon dioxide standard in true mathematical fashion. I also wanted to emphasize that the old carbon dioxide standard was in no sense an error of the engineer; it was an error of the physiologist.

As I see it there are really only two fundamental questions which divide us. We are all agreed that the essential in school ventilation is the maintenance of the effective temperature, which the gentlemen from Pittsburgh have cited, of 66 deg. The first important difference of opinion is as to whether an effective temperature of 66 deg., however arrived at, by whatever combination of temperature, humidity and air motion, is equally satisfactory. Dr. Hill implied that that was so. That is our first point of issue. We are convinced from our studies in New York that while, in general, these effective temperatures are roughly equivalent, yet within that equivalency, when the situation is studied with large numbers of individuals over long periods of time, as we studied it, an effective temperature of 66 obtained with a low flow of cool air is more comfortable than the same effective temperatures obtained with a high flow of warm air.

There is certainly nothing in the Pittsburgh work to contradict that conclusion and I would like to say that our results in that respect were obtained in exactly the same way that the results at Pittsburgh were derived—by expressions of individuals as to their sensations of comfort; only that we worked in a smaller range with smaller variations and with a larger number of people over a longer period. That is the first problem upon which we shall have to come to an agreement if we are not going to continue in a state of war.

If this conclusion is justified, if it proves that we are right in feeling that a low flow of cool air is better than a high flow of warm air, then inevitably the 30 cu. ft. standard falls by the wayside, as at least needless if not harmful, and no atom of new evidence has been presented here of any kind to show that the 30 cu. ft. of air standard is necessary for health or comfort.

Something has been said about the mechanical conditions which obtained in the fan ventilated schoolrooms studied by our Commission in New York, but these criticisms do not in the least bear upon the practical conclusions obtained. If you will study the detailed data in the report of the Commission you will find that, imperfect as they were, these systems gave an ample air flow; that judged by air flow and carbon dioxide those fan rooms differed from the window rooms in two respects—higher air flow and lower carbon dioxide—if they had been more perfect they would have given still higher air flow and still lower carbon dioxide. Yet one fundamental complaint with them as they stand is that they gave too great an air flow.

If the 30 cu. ft. standard is unnecessary it seems clear that experimentation and practice should no longer be limited by the imposition of a legal standard which prohibits other procedures. The 30 cu. ft. standard in itself has of course nothing necessarily in theory to do with window or fan ventilation; but with window ventilation you cannot constantly obtain as high an air flow as that while with

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fan ventilation you can obtain a higher air flow or a lower air flow as desired.

If we were to proceed so far and were to agree (which we certainly cannot as yet) that the 30 cu. ft. law was unnecessary and that the desirable condition was as the N. Y. Commission believed—the supply of a smaller volume of cool air—there would still remain of course the possibility of using fan ventilation with a low velocity. Personally I have no objection to that from the standpoint of health provided the fans are cut down to the point of supplying only a small volume of cool air. If you do that, however—then you don't need to have the fans—because our results on very large numbers of schoolrooms under actual conditions show that you can obtain that condition by the window-gravity process. These are not theories. They are concrete observations and you will find the full records in the report of the Commission.

The window-gravity rooms we studied were not designed for the purpose for the most part; they were largely ordinary rooms in ordinary schools, operated by closing off the supply duct and installing window boards. They worked; they gave the analytical results. They gave freedom from odor and they gave comfort and health.

That experience cannot be met by oratory however brilliant, but only by facts of some other kind. Such facts are not, as far as I can see, forthcoming this afternoon.

Just one word or two about the question of cost. The conditions that are laid down as ideal conditions for window-gravity ventilation in the New York report are very extreme conditions, very ideal conditions, and in making cost estimates it is not fair to compare that ideal (with its very small number of pupils in a classroom and a very large exhaust duct) with anything but equally ideal and extreme fan ventilation.

As a matter of fact let me remind you that we obtained these entirely satisfactory results discussed above with schoolrooms that had no excess radiation in them. You will find the actual figures all set down in the report. There was no more radiation in the window-gravity rooms than in the fan rooms and yet they operated with perfect success in the climate of New England. There was certainly no possibility of any excess cost, because they were built as fan buildings for the most part and used by merely dropping out the fan part of the system. In the one case in Fairfield, Connecticut, where we had a building designed as a window-ventilated building, that, too, had approximately the same heating surface that the fan-ventilated buildings had.

It is possible of course to save money by recirculation and it may be that process will come into more general use. From our experience, however, while we found it worked no damage to health, we did find it exceedingly difficult to obtain the type of operation that would avoid serious complaint and I fear that the complete recirculation system is likely to prove a very difficult one to apply in practice.

This point is, as I say, the second point. The first point is whether you want a low flow of cool air instead of a high flow of hot air. The second point is whether you can obtain a low flow of cool air by the method of modified window-gravity ventilation. We found in experiments lasting over years and in hundreds of schoolrooms that we could obtain excellent results by that method. Very likely you can obtain equally good results by some other method, but you have got to show us.

This afternoon I do not think that anything but opinion has been offered that contradicts our conclusions in any serious degree. There have been no figures of

experiments. Our work was imperfect, no doubt, but has anything better been presented here? Has anything seriously criticizing our two major contentions been offered in the shape of evidence? The only thing approximating it was the statement from St. Louis as to the general results obtained in that city by the use of fans.

That reminds me of a bit of history. The resolution that was adopted at the meeting of the *American Public Health Association* was not introduced at my suggestion. I helped draft it, but it was introduced entirely at the instance of a physician in St. Louis who was so impatient with the regulations for mechanical and ozonized ventilation in the St. Louis schools and their exceedingly bad results that he urged that the Association should go on record to that purpose.

Dean Anderson said that Dr. Fronczak had nothing on which to base his assertions. I am glad, bye the bye, that Dr. Fronczak spoke to you. I like you to see what we have to deal with, because Dr. Fronczak is a pretty fair representative of the general feeling on the part of the medical profession and I think you will see that I am a very moderate mild gentleman by comparison, nevertheless Dr. Fronczak *has* something on which to base his opinion. He has 20 years' experience with schools in operation.

Gentlemen, our schools are designed excellently, but the architect and engineer do not know as much about what actually goes on afterwards as the doctors and the teachers do and I warn you that if this matter is to be approached as Dean Anderson has suggested in the shape of a battle to the death, Dr. Fronczak's identification of the corpse in the end may not prove far wrong. The physicians and the teachers of this country are becoming very impatient. It is a widespread movement and if you will inquire you will find there is hardly a large city in the country where people are not experimenting with these things. I believe from my experience that in 99 cases out of 100 they are enthusiastic about the window system and condemnatory about the other. That is a situation, gentlemen, and not a theory and if Dean Anderson wants a fight I can tell him that the fight will go on.

The report of the New York State Commission was made in 1923. I deliberately held back those who were anxious to advertise that report at first. I said, "We won't have any particular publicity about this; we will wait and see. We will see if these conclusions are sound; we will see if there is anything to be said on the other side." We waited for two years and the report gradually sank in and nothing in the way of serious experimental evidence was presented on the other side. Then I said to the people who were interested in this subject, "All right, I don't know why you shouldn't go ahead." They are going ahead.

We ought to get together on this thing if we can. I should welcome, as I have said, cooperation in the working out of reasonable alternative standards. Those standards must be based not on opinions, not on eloquence but on the actual evidence of experience and experiment with actual procedures. Any evidence that you have as to the actual working out of systems from the standpoint of comfort or health, you will find physicians, physiologists and public health workers eager to receive and to consider, but these questions must be settled on the basis of the evidence at hand and the evidence accumulated by the New York State Commission in the main in regard to those two major points on which I spoke has not in my judgment been seriously jeopardized by any similar body of evidence on the other side.

Let's have the facts and let's try if we can to get together on the basis of those

facts to do what is best and to attain that ideal of fresh air which Dean Anderson pictured to us in citing Mr. Baldwin's book. That is all we are aiming at, either of us, on either side. It is fresh air in the real sense of the term. If we are wrong as to what constitutes fresh air, we will want to be shown, but if we are right in what constitutes fresh air then the course we are advocating is bound in the end to prevail.

THE CONCENSUS OF OPINION

F. D. MENSING: I wish to present this resolution:

Resolved: That the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS appreciates the fact that the *American Public Health Association* earnestly desires to endorse that condition of ventilation which is calculated to give greatest health and comfort to the occupants of places of assembly. THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS has been working diligently for many years through the Research Laboratory in connection with the U. S. Bureau of Mines and the U. S. Public Health Service to determine scientifically the required conditions to produce the greatest comfort.

Therefore, the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS solicits the cooperation of the *American Public Health Association* in making this determination.

In offering this resolution I think I can say as a member that we are willing to back it up with our money to find the truth. How far will the others go?

W. A. ROWE: I would like to offer a resolution as I believe that we are up against a very serious condition because of the importance which will be assigned to the resolution of the *American Public Health Association* and I think we would pass an opportunity to put this Society on record if we don't take some action at this meeting. For that reason I drew up this resolution:

Resolved: That it is the sense of this meeting that it would be a grave mistake to advocate the repeal of present ventilation laws which require installations in accordance with present standards until something better than present practice can be agreed upon; that present ventilation standards are the result of many years of practical experience and present laws based on those standards have been a positive influence for good; that the wholesale letting down of the bars to permit anything so indefinite as window ventilation would be a step backward and would result in a chaotic condition detrimental to the public health and best interests of mankind.

J. A. DONNELLY: I second Mr. Rowe's resolution.

THORNTON LEWIS: As it stands we have not offered any positive evidence of the failure of the gravity vent flues and window inlet method of ventilation as we haven't had time to talk about it. I would like to present this resolution in addition to that which has been presented:

Resolved: That the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS welcome definite air supply information from the *American Public Health Association,* but most definitely disagree with the suggestion that any consistent ventilation can be obtained by air admission through windows with gravity vent flues.

DR. E. V. HILL: I second that resolution.

The motion was seconded and carried, following which the session adjourned.

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No. 744

A NEW PSYCHROMETRIC OR HUMIDITY CHART[1]

By CLAUDE A. BULKELEY, WILMINGTON, DEL.

MEMBER

SOME hundreds of millions of years ago, when the earth was young and long before the first spark of life could have existed thereon, there was comparatively little or no liquid water on the surface of the earth; it was all in the form of steam at a temperature of about 700 deg. fahr. The atmospheric pressure at the surface of the earth was close to 3200 lb. per sq. in., or over 6000 in. barometric pressure. To say the least the atmosphere was both hot and humid.

Ever since that time the earth's surface has been slowly cooling. When its temperature reaches hundreds of degrees below zero, in the tens of millions of years to come, the gases of our atmosphere will have been condensed into liquids. During this entire period, beginning before the dawn of life and until the planet becomes dead and cold with no atmosphere, water vapor always has and always will be present in the air.

This presence of water vapor in the air is vitally necessary to the very existence of life in all its forms, and the amount present at different temperatures has much to do with our health and bodily comfort.

When it comes to our modern industries, there are many processes of manufacture where a predetermined amount of moisture in the air, as well as its temperature, is very necessary in order that both quantity and quality production be obtained.

Some have specialized and are already thoroughly familiar with so-called air conditioning. However, it is well to review certain fundamental principles underlying the subject on which any psychrometric chart or tables must be based.

Liquids at ordinary temperatures and many solids are volatile and constantly give off vapor which mixes with the air. The amount of this vapor mixed with air depends upon these conditions:

1. The temperature and pressure of the air.
2. The temperature and vapor pressure of the liquid or solid.

At saturation, the ratio of the vapor pressure of the liquid and the barometric pressures of the air, is always equal to the ratio of the vapor and air volumes. For example, the vapor pressure of water at 100 deg. fahr. is 49 millimeters of mercury,

[1] All temperatures are in fahrenheit.

Paper presented at the Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Buffalo, N. Y., January, 1926.

while normal pressure of the atmosphere is 760 millimeters (29.92 in.). Therefore, the ratio by volume of the water vapor and air in the mixture at 100 deg. fahr. consists of $\frac{49}{760} = 6.45$ per cent water vapor and 93.55 per cent air. If the mixture at this temperature contains less than 6.45 per cent by volume of water vapor, it is not saturated, and it is said to have a relative humidity of something less than 100 per cent.

All psychrometric tables such as those issued by the U. S. Government are based entirely upon the vapor pressure of water at different temperatures, taken together with the atmospheric pressure and temperature. At a given temperature, air can hold only a known amount of water vapor, and this amount is dependent upon the vapor tension or pressure of water (or that over ice below 32 deg.).

Below a temperature of 212 deg. fahr. the vapor tension of water at any temperature is identical with that given in the vacuum steam tables, and the weight of water vapor contained in 1 cu. ft. of a saturated mixture weighs the same as given in the vacuum tables for weight of 1 cu. ft. of steam. This must be kept in mind in order to have a clear understanding of the underlying principles of air conditioning, the psychrometric tables and relative humidity.

What is known as relative humidity is the ratio between the number of grains of moisture contained in a cubic foot of the mixture at a given temperature and the number of grains per cubic foot which the mixture could contain if it were saturated. When additional moisture is present in the mixture it is super- or over-saturated, and this additional moisture shows itself as fog.

Furthermore, a partial saturation of the water vapor is superheated. At any dry-bulb temperature, the per cent of relative humidity is always equal to the ratio of the vapor pressures at the dew point and saturated dry-bulb temperatures. For example: at 10 per cent relative humidity and at dry-bulb temperatures of 100 deg., the dew point is 33.7 deg. having vapor pressure of 4.9 millimeters while at 100 deg. the vapor pressure is 49 at saturation, therefore $4.9 \div 49 = 10$ per cent.

On the accompanying chart, Fig. 1, the vapor pressures are plotted in vertical direction to logarithmic scale. The advantages of doing this are apparent by referring to Fig. 2. On the upper left hand portion of the figure the vapor pressures of water are plotted on logarithmic scale ordinates, and temperatures on arithmetic scale abscissa. On the lower right hand portion of the figure the vapor pressures and tem- peratures are both plotted on arithmetic coordinates. A chart of this character is used most frequently between the temperatures of 0 deg. and 100 deg. fahr., and seldom higher than 140 deg.

If arithmetic scale is used for both vertical and horizontal coordinates, the vertical spacings become nearly sixty times as great per degree at 140 deg. as at 0 deg.; this means that to make the lower degree intervals legible, those at the higher temperature become too great to plot on a chart of workable size. However, when the vertical ordinates are to logarithmic scale, the vertical spacings instead of being greater, are approximately one half as much per degree at 140 deg. as at 0 deg. This means that a chart laid out with vertical logarithmic ordinate values has relatively small difference per degree interval throughout the entire working range. In fact the intervals are somewhat greater at the lower temperatures. This latter is an advantage since the difference in vapor pressure per degree is less. The above comparison between the two methods of plotting is indicated by the relative height of the two rectangles *A* and *B*, Fig. 2.

In preparing the chart, the vapor pressure or saturation line was arbitrarily

drawn between the lower left and upper right hand corners, the slope of this line determining the length relative to height of the chart. Degree intervals were made to conform to differences in vapor pressure. It will be noted that this method of plotting makes the temperature scale also logarithmic, furthermore, that the temperature scale changes at 32 deg. due to vapor pressures being those over ice below 32 deg.

Making the vapor pressure or saturation line straight, and thus not using arithmetic temperature or abscissa intervals, makes all relative humidity lines straight. To correctly draw these lines on the chart it was only necessary to read the saturated vapor pressures at a low and high temperature and multiply each by the given per cent relative humidity. The product in each case is the vapor pressure at the given relative humidity located by points on the dry-bulb temperature lines at each end. Connecting these two points by a straight line gives the correct location of the relative humidity line for each intervening dry-bulb temperature. Each line also crosses each dry-bulb line at the correct dew point.

The dew point or proper location for the wet-bulb line at any dry-bulb temperature was determined by W. H. Carrier's Rational Psychrometric Formula (see page 1024, 1911 *Transactions A.S.M.E.*). This formula is as follows:

Wet-bulb temperatures of 32 deg. and above.

E = Vapor pressure at dew point
e' = Vapor pressure at wet-bulb temperature (saturated)
B = Barometric pressure
t = Dry-bulb temperature
t' = Wet-bulb temperature.

$$E = e' - \frac{(B-e')(t-t')}{2800-1.3t'}$$

For each given wet bulb the formula becomes

$$E = e' - \left[\left(\frac{B-e'}{2800-1.3t'}\right)(t-t')\right]$$

Since the fraction in the equation is the same for all dry-bulb temperatures only one multiplication is required, and the product subtracted from e' to obtain the vapor pressure at dew point for the desired dry-bulb temperature.

Having calculated the vapor pressure of the desired dew point, the corresponding temperature is found on the chart. The intersection of this dew point line and the dry-bulb line is the desired point for the crossing of the wet-bulb line.

For wet-bulb temperatures below 32 deg. the formula becomes

$$E = e' - \frac{(B-e')(t-t')}{3170-1.36t'}$$

The formulae are the same, whether pressures are in millimeters or inches of mercury, providing all pressures in one calculation are in one or the other. Millimeters rather than inches of mercury are used on the chart since each unit is smaller and is more adaptable to decimal plotting required with logarithmic scale.

Description of Chart

Vapor pressures at different temperatures are plotted on the vertical ordinate in millimeters of mercury to logarithmic scale. The saturation line is the upper

diagonal straight line running between lower left and upper right hand corners of the chart. The relative humidity lines are those parallel to and below the saturation line. All vertical lines on the chart are dry-bulb temperatures. All horizontal lines to the right of saturation line are dew point temperatures. For the convenience of any who may prefer it, the equivalent centigrade temperatures are given at bottom and right side of chart. The wet-bulb lines are those curving downward to right of saturation line.

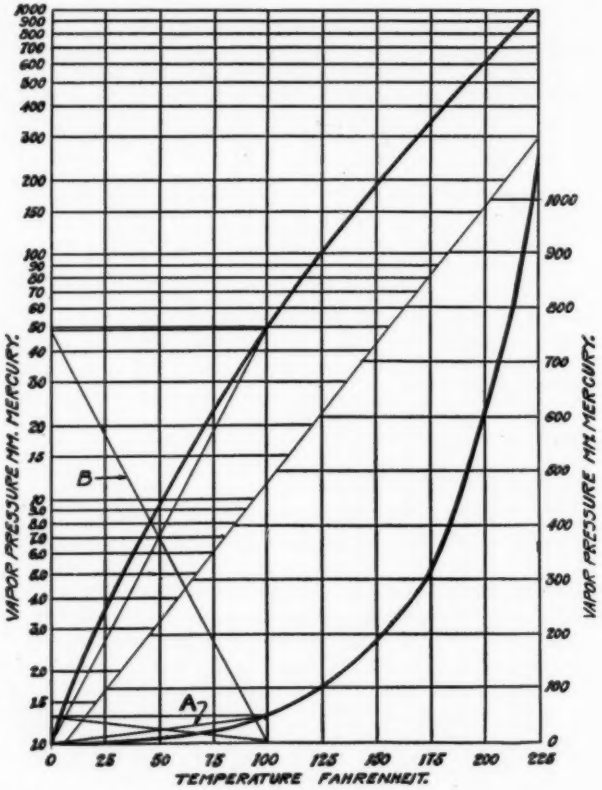


FIG. 2. COMPARISON BETWEEN LOGARITHMIC AND ARITHMETIC PLOTTING ON BULKELEY CHART

The directrix curves above the saturation line are as follows:

"*A*" Is the total heat in B.t.u. contained in the mixture above zero fahrenheit, and is to be referred to column of figures at left side of chart. The hook in this curve at 32 deg. dry bulb is due to the latent heat of fusion.

"*B*" Is grains of moisture of water vapor contained in each pound of the saturated mixture and is to be referred to figures at left side of chart.

"C" Is grains of moisture or water vapor per cubic foot of saturated mixture, and is to be referred to figures at left side of chart and divided by ten.

"D" Is weight in decimal fractions of a pound, of one cubic foot of the saturated mixture, and is referred to the first column of figures to the right of the saturation line between vertical dry-bulb temperature lines 170 and 180 deg. The relative density of the mixture is in similar manner read from the same curve by the column of figures between the vertical dry-bulb lines 180 and 190 deg.

"E" Is similar to *"D"* but is for dry air, devoid of all moisture or water vapor. For convenience, the approximate absolute temperature of 500 deg. fahr. is given at 40 deg. fahr. on the saturation line for the purpose of calculating volume, weight per cubic foot and relative density at partial saturation.

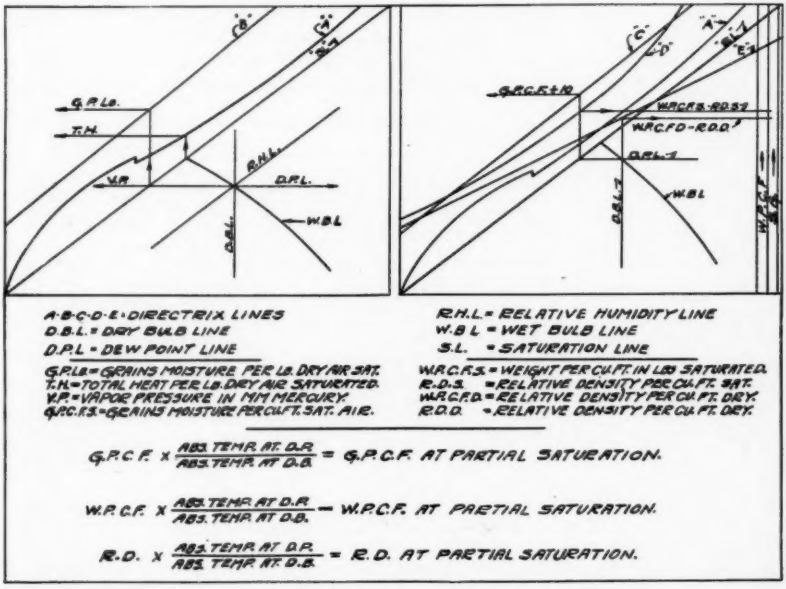

A·B·C·D·E·DIRECTRIX LINES
D.B.L. = DRY BULB LINE
D.P.L. = DEW POINT LINE
G.P.L.B. = GRAINS MOISTURE PER LB. DRY AIR SAT.
T.H. = TOTAL HEAT PER LB. DRY AIR SATURATED.
V.P. = VAPOR PRESSURE IN MM MERCURY.
G.P.C.F.S. = GRAINS MOISTURE PER CU.FT. SAT. AIR.
R.H.L. = RELATIVE HUMIDITY LINE
W.B.L. = WET BULB LINE
S.L. = SATURATION LINE
W.P.C.F.S. = WEIGHT PER CU.FT. IN LBS SATURATED.
R.D.S. = RELATIVE DENSITY PER CU.FT. SAT.
W.P.C.F.D. = RELATIVE DENSITY PER CU.FT. DRY.
R.D.D. = RELATIVE DENSITY PER CU.FT. DRY.
G.P.C.F. × ABS. TEMP. AT D.P. / ABS. TEMP. AT D.B. = G.P.C.F. AT PARTIAL SATURATION.
W.P.C.F. × ABS. TEMP. AT D.P. / ABS. TEMP. AT D.B. = W.P.C.F. AT PARTIAL SATURATION.
R.D. × ABS. TEMP. AT D.P. / ABS. TEMP. AT D.B. = R.D. AT PARTIAL SATURATION.

FIG. 3. DIAGRAMS SHOWING PROCEDURE TO FOLLOW IN USING BULKELEY CHART

Examples in Use of Chart

CONDITIONS: 95 deg. dry bulb and 78 deg. wet bulb in Examples 1 to 6, inclusive.

Example 1—Relative humidity: At intersection of 78 deg. wet bulb and 95 deg. dry bulb the relative humidity is read directly on the straight diagonal lines as 45.7 per cent.

Example 2—Dew point: At intersection of 78 deg. wet bulb and 95 deg. dry bulb lines, the dew point is read directly on horizontal temperature lines as 70.9 deg.

Example 3—Vapor pressure: At intersection of 78 deg. wet bulb and 95 deg.

dry bulb lines, pass in horizontal direction to left of chart and on logarithmic scale read the vapor pressure as 19.4 millimeters.

Example 4—Total heat above 0 deg. in mixture per pound of dry air saturated with moisture: From where wet bulb line joins saturation line, run in vertical direction on 78 deg. dry bulb line to its intersection with curve "*A*" and on logarithmic scale at left of chart read 40.6 B.t.u. per lb. of mixture. The use of this curve to obtain total heat in the mixture at any wet-bulb temperature is a great convenience, as the number of B.t.u. required to heat the mixture and humidify, as well as the refrigeration required to cool and dehumidify the mixture, can be obtained by taking the difference in total heat before and after treatment of the mixture.

Example 5—Grains of moisture per pound of mixture: From dew point 70.9 deg. on saturation line, run vertical to intersection with curve "*B*" and on logarithmic scale on left read 114 grains of moisture per pound.

Example 6—Grains of moisture per cubic foot of mixture, partially saturated: From dew point 70.9 deg. on saturation line proceed in vertical direction to curve "*C*," and on logarithmic scale to left read 83.3 divided by 10, equals 8.33 grains. 70.9 deg. equals 530.9 deg. absolute temperature and 95 equals 555 deg. absolute temperature. $\frac{530.9}{555} \times 8.33 = 7.97$ grains per cubic foot of partially saturated mixture.

Example 7—Grains of moisture per cubic foot of dry air saturated: Starting at saturation line at desired temperature, run in vertical direction to curve "*C*" and on logarithmic scale, on left, read and divide by 10.

Example 8—Weight per cubic foot of dry air and relative density: From point where, for example, the 70 deg. vertical dry-bulb line intersects curve "*E*," run to right side and read .075 pounds; if cubic feet per pound is desired, divide 1 by this amount. The relative density is read immediately to the right as 1.00.

Example 9—Weight per cubic foot of saturated air and relative density: From point where, for example, the 70 deg. vertical line intersects the curve "*D*," run to the right and read weight per cubic foot as 0.07316 with relative density 0.9755 for saturated air at 70 deg.

Example 10—Weight per cubic foot and relative density of partially saturated air: Take, for example, 50 deg. air at 46 deg. wet bulb and heat it to 130 deg. The wet- and dry-bulb lines intersect at a dew point of 42 deg. Run to left where this dew point line intersects the saturation line and run in vertical direction to where the 42 deg. dry-bulb line intersects with curve "*D*." Then run directly to right and read the weight, per cubic foot of saturated air at 42 deg. as 0.07844 and the relative density as 1.046. The absolute temperature at 42 deg. is 502 deg., and of 130 deg. is 590 deg. $\frac{502}{590} = 0.851$. Weight of 1 cu. ft. of air at 50 deg. dry-bulb and 46 deg. wet bulb when heated to 130 deg. is $0.07844 \times 0.851 = 0.06675$, and the relative density is $1.046 \times 0.851 = 0.89$.

Fig. 3 shows diagrams illustrating procedure to follow in using the chart.

The tables of manufacturers whose fans are tested in accordance with the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS' Code for Testing Fans, are based on 70 deg. dry air. When it is desired to handle other than 70 deg. dry air, the relative density obtained from the chart may be used to determine the correct speed, static pressure and horse power of the fan.

The required capacity in cubic feet per minute at chart density, must be multi-

plied by the square root of the relative density. Select this calculated volume from the fan tables at pressure desired under operating conditions, then divide the speed and horse power found in the tables, by the square root of the relative density.

If the cubic feet per minute, static pressure and horse power are measured under operating conditions, and the air is at other than standard density, the operation of the fan may be checked against fan tables or characteristic performance curves by dividing each the operating static pressure and horse power by the relative density. The cubic feet per minute and speed under operating conditions should give the calculated static pressure and horse power when referred to fan tables or curves.

NOTE 1: The writer wishes to acknowledge his indebtedness to W. H. Carrier for having checked the chart and for giving valuable suggestions regarding dew points and relative humidities.

NOTE 2: Vapor pressures, etc., are those found in Table 6, Mixtures of Air and Saturated Water Vapor in *Properties of Steam and Ammonia*, by G. A. Goodenough.

DISCUSSION

H. P. GANT: Mr. Bulkeley has done a very splendid piece of work and this new chart is a real contribution to the art of heating and ventilating work. While Mr. Bulkeley has given full credit for having based this chart on Mr. Carrier's psychrometric chart, he has made it possible by using the logarithmic scale to use the chart with equal accuracy both in the low and high ranges and I think that that fact cannot be overemphasized.

One criticism that I made when I saw this originally was that I thought it would be very wise if Mr. Bulkeley could use a simple name for it. Instead of using the word *psychrometric* use some simple word that all of us could understand, because to most of us who are not accustomed to using the psychrometric chart continuously it seems like a very complicated proposition. As a matter of fact that chart is really quite simple, after you once get the primary idea involved.

The subject of vapor pressures of various chemicals which was shown in one of the slides by Mr. Bulkeley, was very interesting.

F. D. MENSING: We are going to be faced with two charts named psychrometric. We can't call this entirely the Carrier chart, although it is based on Mr. Carrier's formula. I would like to make a motion so we may differentiate between the two, that we call this the Bulkeley chart, as based on the Carrier formula; the thought being that it is a Bulkeley chart based on the Carrier formula using Mr. Carrier's own term for that formula.

W. H. CARRIER: Rational psychrometric.

F. D. MENSING: So it becomes the Bulkeley chart based on the Carrier rational psychrometric formula.

H. P. GANT: I will second that motion.

PRESIDENT DIBBLE: Does that include anything in reference to this Society accepting this chart?

F. D. MENSING: I was going to make that motion.

E. P. LANGENBERG: I think it would be proper for the Society to copyright this chart, to get credit for it and I would like to have it included in this motion.

F. D. MENSING: I move it be copyrighted and sold at whatever cost the Society may deem proper.

W. H. CARRIER: You have here about the equivalent of three charts and you get an accuracy there at each end that is compatible with the accuracy through the center. Heretofore, that fact has been the drawback with charts made on a purely arithmetic scale. The very ingenious thing about this chart is Mr. Bulkeley's use of approximate logarithmic equations of vapor pressure which if it were exactly true would permit an arithmetic scale at the bottom and a geometric scale for the vapor pressure. The law of all vapor pressures is to build up at a definite ratio for each equal increment an arithmetical increment of temperature. That is approximately so but not exactly so. That is the reason we can control relative humidity by dew point. The discovery of the dew-point method of control was based on this fact. I don't know whether you have appreciated that or not, but with a 20 deg. difference between the dew-point saturation temperature and room temperature, you have practically 50 per cent humidity, and it doesn't matter whether you start with a 30 deg. dew point or a 90 deg. dew point, the law approximately holds. If it were a true logarithmic scale it would hold exactly and this illustrates that fact very well. The lower scale in this particular thing is the use of a variable instead of an arithmetic scale, so that it enables this to become a straight line and have a scale at the bottom which is not arithmetic. The divisions approximately decrease as the absolute temperature increases and that makes, of course, the saturation curve a straight line and makes all the others parallel lines. All you have to do is get two points and you can draw in the whole thing on that basis.

This chart could be arranged in another way, but I don't believe it would be quite as good. It could be gotten up in a logarithmic scale using the weight of mixture per pound of air and the temperature below, but you would have only one curve, probably a straight line in that case. You would make a saturation curve a straight line, but others would begin to curve slightly and at low percentages the curvature would be noticeable.

The advantage of using the vapor pressure, as Mr. Bulkeley has shown, makes these percentage lines absolutely parallel lines with the saturation. Then he goes up to the range per pound.

Another method would involve more work in construction, that is the only difference, and get your readings direct. The same thing can be applied to other vapors beside water, as Mr. Bulkeley has shown, and the whole scheme is a very good scheme for a general mixture of any vapor with air where you have partial pressures involved. Mr. Bulkeley has made a real contribution in the matter of the arrangement of the charts of that information easily reading over wide range.

H. P. GANT: If I may be allowed, I would like to propose a vote of thanks to Mr. Bulkeley for his own personal effort and laborious work in presenting this paper.

No. 745

THE SEMI-ANNUAL MEETING, 1926

THE 32nd Semi-Annual Meeting opened at the Hotel Phoenix, Lexington, Ky., May 26, 1926, with Pres. W. H. Driscoll presiding, and the members were greeted by First Vice-Pres., F. Paul Anderson, Chairman of the Committee on Arrangements, who introduced Mayor Hogan Yancey, Lexington.

At the first session copies of a proposed amendment to the Constitution and By-Laws, suggested by the Kansas City Chapter, was read by Secretary A. V. Hutchinson, and after considerable discussion motion was made by J. F. McIntire, authorizing the President to appoint a Committee of three to take these amendments under advisement and report at a later session with suggestions as to how the Nominating Committee might be handled in an acceptable manner. President Driscoll announced the Committee as John F. Hale, Chicago, Chairman, E. S. Hallett, St. Louis, Roswell Farnham, Buffalo.

Three technical papers were presented at the first session, Humid Air as a Heating Medium, by Foskett Brown, Nashville, Tenn.; Development of the Art of Heating and Ventilating in Canada, by Prof. L. M. Arkley, Queens College, Kingston, Ont.; and Experiment in Insulating a Home, by H. S. Ashenhurst and S. R. Lewis, Chicago.

The second session was devoted to Research and the first paper given was by Prof. F. B. Rowley, Minneapolis, entitled Some Results in Heat Transmission Research.

H. P. Gant then took the chair and gave his report as chairman of the Committee on Research followed by a report from Director F. C. Houghten and several Technical Advisory Committees.

Report of Committee on Research

The report of the Chairman of the Research Committee will be very brief, but very optimistic. In past years it has frequently been necessary for the Chairman of the Research Committee to come before you and shed bitter tears in imploring you to contribute to the financial support of the Laboratory. This year, however, no such unpleasant duty devolves upon the Chairman as the ten dollars a year which each member pays toward the support of the Laboratory has placed us on a very satisfactory financial basis.

Our operation of the Laboratory is worked on a budget and the budget is based on the income which we derive from the $10.00 from each member, and private contributions. The limit of our work at the Laboratory is governed by the limit of money available.

The Laboratory is not proud, and any contributions that any members or any organizations care to make will be very gladly and gratefully accepted so I hope you will not feel that because we have sufficient income to care for our present budget, more money cannot be used advantageously.

Last year, under the very able chairmanship of Pres. Driscoll, the method of handling the work of the Laboratory was reorganized and put under various technical advisory committees.

If you will refer to any recent JOURNAL, you will see that there are six technical advisory committees, whose duty it is to handle various subjects and to cooperate with the director and the personnel of the Laboratory. Those six technical advisory committees consist of the Committee on Subjects, S. R. Lewis, chairman; Committee on Infiltration, Prof. A. C. Willard, chairman; Committee on Radiation, R. V. Frost, chairman; Committee on Pipe Sizes, J. A. Donnelly, chairman; Committee on Temperature, Humidity and Air Motion, W. H. Carrier, chairman; Committee on Heat Transmission through Building Materials, L. A. Harding, chairman.

That, as you note, makes a six-cylinder engine. Feeling, however, that we must keep pace with the progress of the times, we have decided to make this machine an eight-cylinder engine instead of six, and we have added two technical advisory committees which are the Committee on Rating Low Pressure Heating Boilers, A. C. Kellogg, of Boston, Chairman, and the Committee on Chimney Sizes for Low Pressure Heating Boilers, with J. R. McColl as chairman.

The work of the Laboratory has been progressing in excellent shape and our machine is running smoothly and it is our hope in the very near future to send all members, contributors and all those who are interested in the work of the Laboratory, a periodical, brief, condensed report of the work being done at the Laboratory.

Of course, you know that since the inception of the Laboratory, all of the work that has been done there has been fully reported in THE JOURNAL in detailed form. Some of this information, however, is not usable to the layman, and consequently, we will endeavor very shortly to take that data, condense it, abridge it, and put it out in loose-leaf bulletin form so that it may be used for ready reference, and we may make better use of the splendid work that has been done by the Laboratory.

Respectfully submitted,

H. P. GANT, *Chairman*

The concluding paper of the session on the Development of Characteristics of a Carbon Monoxide Recorder was given by S. H. Katz of the Bureau of Mines, Pittsburgh.

At the final session of the meeting on Friday, May 28, four papers were given: the Friction of Water in Elbows by Prof. F. E. Giesecke, Austin, Texas, was read by R. V. Frost, Norristown, Pa.; Observing Warm Air in Circulation was the subject of Thornton Lewis, Philadelphia, Pa., and a very complete analysis of Ventilation Studies was given by Dr. J. E. Rush of the University of Kentucky, in his paper, Rational Ventilation. The next speaker was J. R. McColl, Detroit, who spoke on Heating and Ventilating a School without Direct Radiation.

At the conclusion of the technical program, President Driscoll asked John F. Hale to report for the Special Committee on Revision of By-Laws. Mr. Hale stated that his committee had talked with a great number of members from all parts of the country and though considerable diversity of opinion was noticeable, the committee had arrived at a conclusion which it was believed would solve the difficulty and were pleased to offer the following resolution relating to the appointment of the Nominating Committee.

Report of Committee to Investigate the Proposed Amendments to the By-Laws of the Society

Your Committee, appointed by the Chair to investigate the question of proposed amendments to the By-Laws of the Society, has had several meetings, at which the various members have been present, and discussed the points in question.

XUM

Your Committee proposes the following substitutions for the proposal made by the Kansas City Chapter:

AMENDMENT NO. 1

Article No. 9, Section 2, of the By-Laws to read as follows:

A. The Nominating Committee shall consist of a member designated by each Chapter, which shall effect its own organization and elect its own Chairman.

B. The Committee may meet at the call of the Chairman, for discussion, but the official meeting shall be held at the Semi-Annual Meeting of the Society, at which time the candidates for each of the offices of the Society to be filled at the next Annual Meeting shall be selected by a majority vote of the members of the committee present and voting. Five shall constitute a quorum.

C. The Committee shall first secure the consent of all candidates selected, and shall if possible announce the names of the candidates at the Semi-Annual Meeting, but in any case the names of candidates shall be certified to the Secretary of the Society at least four months before the next Annual Meeting. The Secretary shall publish these names in the October issue of THE JOURNAL.

AMENDMENT NO. 2

Article 9, Section 8. Any amendments or changes in these By-Laws which affect the selection of the Nominating Committee shall become effective only after the next Annual Meeting of the Society following the adoption of such amendments or changes.

EDWIN S. HALLETT
ROSWELL FARNHAM
JOHN F. HALE, *Chairman*

Dr. E. Vernon Hill, speaking in favor of the resolution, stated that in his opinion there was a demand for chapter representation on the Nominating Committee and felt that resolutions offered by the special committee had answered all objections. He then made a motion that these amendments in which he concurred wholeheartedly be adopted by the Society. Motion was seconded by E. P. Heckel.

Thornton Lewis, Philadelphia, inquired whether there was a definite provision for certification of chapter representatives to the Secretary of the National Society and then offered an amendment that the Council have power to add to these amendments as written sufficient details to fix a definite time for designation and certification of chapter members. The motion as amended was seconded by F. D. Mensing. The amendment when voted upon was unanimously carried.

Lexington was voted a great meeting place by the 225 members who attended the 32nd Semi-Annual Meeting and everyone enjoyed the taste of true Southern hospitality where "The bluegrass waves the bluest, the sun shines ever brightest and Life's burden bears the lightest—In Kentucky."

While the men participated in a golf tournament at the Ashland Golf Club conducted by R. C. Bolsinger, Philadelphia, the ladies enjoyed a luncheon and bridge in the club house. On Thursday the Society members were guests of the University of Kentucky where a Burgoo Luncheon was served on the Campus and in the evening everyone attended the Engineers' Dance at the University Gym. On Friday afternoon the Society members and guests visited some of the famous stock farms in the bluegrass country and each one was presented to the famous Man-o'-War.

In the evening the usual dinner dance was held at the Hotel Phoenix with President Driscoll acting as toastmaster. This dinner was in the nature of a testimonial to the Past Presidents of the Society and was featured by the presentation of the Past President's Emblem to D. M. Quay, Cleveland; J. D. Hoffman, Lafayette, Ind.; John F. Hale, Chicago; J. I. Lyle, Newark; F. R. Still, New York; Dr. E.

V. Hill, Chicago; and J. R. McColl, Detroit. Those who could not attend this ceremony but who received the emblems at a later time were Henry Adams, Baltimore; R. P. Bolton, New York; John Gormly, Norristown, Pa.; H. M. Hart, Chicago; Stewart A. Jellett, Philadelphia; D. D. Kimball, New York; J. H. Kinealy, St. Louis; Samuel R. Lewis, Chicago; C. L. Riley, New York; W. G. Snow, Boston; C. B. J. Snyder, New York; and W. S. Timmis, New York.

The speakers of the evening were F. L. McVey, President of the University of Kentucky, Colonel C. H. Morrow, and E. P. Morrow, former Governor of Kentucky.

PROGRAM 32ND SEMI-ANNUAL MEETING

AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS

Hotel Phoenix, Lexington, Ky., May 26–28

First Session, Wednesday, May 26, 10 a.m.

Registration
Greeting by Mayor Yancey of Lexington
Response by Pres. W. H. Driscoll
Discussion—Amendments to By-Laws
Paper:
Humid Air as a Heating Medium, Foskett Brown, Nashville, Tenn.
Paper:
Development of the Art of Heating and Ventilation in Canada, Prof. L. M. Arkley, Queen's University, Kingston, Ontario
Paper:
An Experiment in Insulating a Home, H. S. Ashenhurst and S. R. Lewis, Chicago, Ill.
Paper:
Friction of Water in 90 and 45 Degree Elbows, F. E. Giesecke, University of Texas, Austin, Texas

Second Session, Thursday, May 27, 10 a.m.

Paper:
Some Results of Heat Transmission Research, F. B. Rowley, University of Minnesota, Minneapolis, Minn.
Report of Committee on Research, H. P. Gant, Chairman
Report of the Director, F. C. Houghten
Reports of Technical Advisory Committees of Committee on Research, W. H. Carrier, J. A. Donnelly, R. V. Frost, A. C. Willard, L. A. Harding, Alfred Kellogg
Paper:
Effective Temperatures for Persons Lightly Clothed and Working in Still Air, F. C. Houghten, W. W. Teague, W. E. Miller
Paper:
Work Tests Conducted in Atmospheres of Low Temperature in Still and Moving Air, W. J. McConnell, Philadelphia, Pa., and C. P. Yaglou, Boston, Mass.
Paper:
Development and Characteristics of a Carbon Monoxide Recorder, S. H. Katz, U. S. Bureau of Mines, Pittsburgh, Pa.

Third Session, Friday, May 28, 10 a.m.

Paper:
Heating and Ventilating a School without Direct Radiation, J. R. McColl, Detroit, Mich.
Paper:
Observing Warm Air in Circulation, Thornton Lewis, Philadelphia, Pa.
Paper:
Rational Ventilation, Dr. J. E. Rush, University of Kentucky, Lexington, Ky.

XUM

No. 746

AN EXPERIMENT IN INSULATING A HOME

By H. S. Ashenhurst (Non-Member) and Samuel R. Lewis (Member)

CHICAGO, ILL.

AN EXPERIMENT in house insulation was started in 1925 and the record of results so far is of peculiar interest to heating engineers for no one can predict how far present-day principles of design may be affected.

The frame residence under discussion, Fig. 1, the home of Mr. Ashenhurst, was built in Chicago in the summer of 1925. No particularly unconventional features were incorporated in its construction except as follows:

The first floor has insulex between the nailing strips. The spaces between the rafters above the second story are filled in the same manner. All spaces between the outside wall studs are filled with the same material.

Insulex is to all intents and purposes plaster of paris mixed with water and with a substance which, when wet, forms rather slowly a harmless gas expanding the plaster of paris or gypsum into a spongy mass which, when it sets, results in an infinite number of very small air spaces. The process is analogous to that which transforms a mass of dough into an angel food cake.

The house has a plaster board Craftex interior with a wood sheathing and wood shingle exterior. The insulating material was poured into the wall spaces while in a fluid state, filling the spaces solidly before setting. When set, the gypsum is rock-hard, and is of course an excellent deterrent of fire and vermin.

There is about $3^5/_8$ in. of insulation in the walls and roof, and 2 in. in the first floor. Dry wood is well known to have a very low heat transmission rate, and the fact that the studs and other timbers break the continuity of the insulex seems to have no particularly objectionable effect. The insulation, as described, for the complete house cost, at standard market prices, $432.00.

Storm sash was installed in December. No weather stripping was used, and no attempt made to make windows tight.

Two independent organizations, using their own modifications of standard formulas for heat transmission, ignoring the insulation in the house, computed the amount of radiation required for gravity circulation hot water heating. They agreed within 8 sq. ft.

Paper presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, Lexington, Ky., May, 1926.

The following is a tabulation of the radiation as computed for an uninsulated house, and as installed for the insulated house.

	Computed	Installed
Chamber No. 1	78	48
Bath	20	15
Chamber No.	51	32
Stair Hall	58	
Kitchen	37	52.5
Dining Room	130	72
Living Room	120	72
Bedroom	81	
Bedroom	136	30
Total	711	321.5

FIG. 1. THE ASHENHURST RESIDENCE IN CHICAGO

The Peoples Gas Company of Chicago made the following estimate of the cost of heating the house, the floor plans of which are shown in Figs. 2 and 3.

Experience shows an average cost of $3.25 per season per 1000 B.t.u. per hour rating. On the basis of 711 sq. ft. at 150 B.t.u. per sq. ft. per hour this estimate gives $344.50 per season to heat the uninsulated house with gas.

A Bryant 402 gas boiler rated at 425 sq. ft. was installed. It was equipped with the usual Minneapolis thermostat, having the customary clock attachment for maintaining a lower temperature at night.

If $2.00 per sq. ft. of radiation is a fair cost to the owner for a hot-water heating plant, the plant as installed saved 389.5 sq. ft. at $2.00 per sq. ft., or $779.00 ($779.00 −$347.00). So far then, a net saving of $347.00 in the original investment was accomplished by insulating the house, to say nothing of any coincident advantages.

The natural question is, What results are being obtained? Is the house comfortable? What does the gas cost?

Two two-pen recording thermometers were in operation in the house all winter, one in the living room recording interior and outside temperatures; the other in an upstairs bedroom recording the interior temperature and that in the peak of the roof above the insulation.

The coldest day this winter was Saturday, December 26, 1925, when the outside temperature was —16 deg. At this time only three of the four gas burners were turned on, and this for only one hour. During the balance of the day but two burners were operated, and the temperature in the house stayed at 70 deg. The water temperature reached 140 deg. for a short time only, and the thermostat

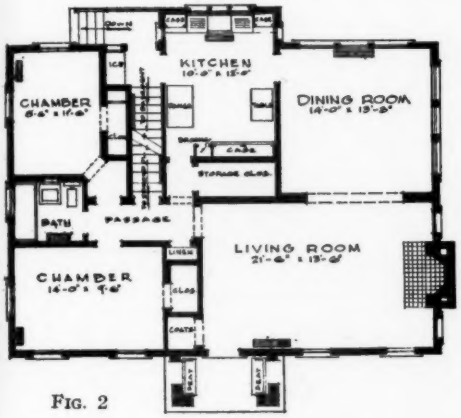


FIG. 2

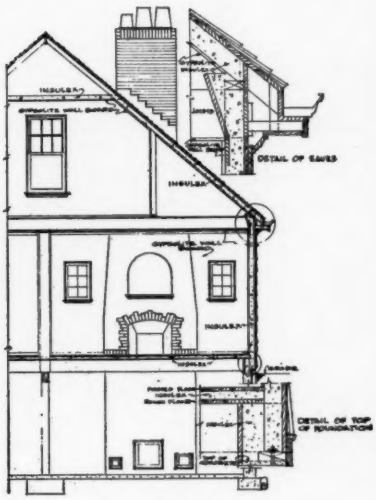
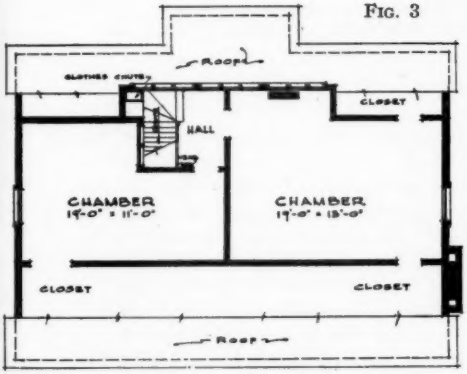


FIG. 4

FIG. 3



FLOOR PLANS AND ELEVATION OF ASHENHURST RESIDENCE

kept the gas shut off except for the pilot flame, for 7½ hrs. of the 24 hrs. of that day. During outside temperatures of 30 deg. or higher, it has been found necessary to use but one of the four burners to maintain 70 deg. with water at a maximum of 110 deg.

During the past winter, the 30 sq. ft. radiator on the second story has been kept shut off. The rooms were only occupied at nights for sleeping, and were maintained at 60 deg. during the day by the leakage through the uninsulated ceiling of

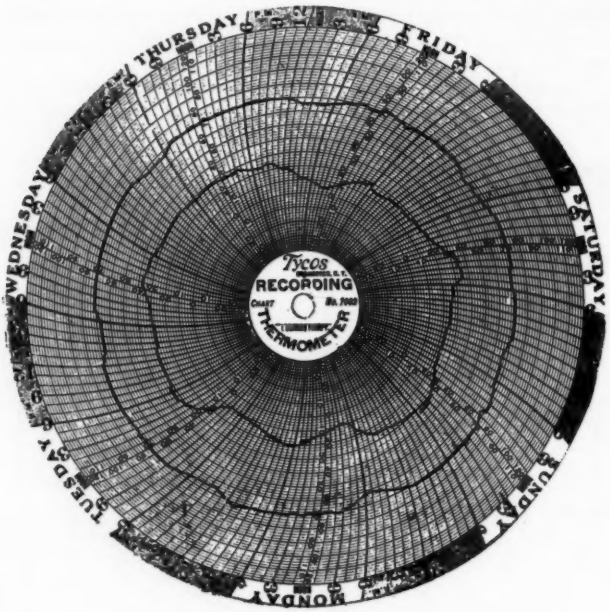


FIG. 5. CHART SHOWING OUTSIDE TEMPERATURE AND LIVING ROOM TEMPERATURE FOR ONE WEEK

the rooms below; the insulation in the upper ceiling preventing the leakage of the heat into the attic space.

Two charts are presented. Fig. 5 shows the outside temperatures and the temperatures in the living room for one week. As low as +6 deg. outside was indicated while the inside temperatures were maintained at 70 deg. during the day.

In Fig. 6 it will be seen that the temperature in the second story was maintained at 60 deg. during the day. The inside line on Fig. 5 shows the temperature in the peak of the roof above the insulation. These temperatures were maintained without the radiator being turned on.

One of the interesting features connected with the heating of the house was the low temperature maintained in the boiler. These readings were taken each morning at eight o'clock—the time of the daily meter reading, and about the time of the warmest water. Here are a few of these readings taken at random:

	Temperature, Degrees Fahr.		
	Outside	Water	Interior
Feb. 19	4	108	70
Feb. 23	20	106	70
Mar. 4	10	134	70
Mar. 8	6	138	70
Mar. 11	2	124	70
Mar. 29	22	110	70

The high reading on March 4 for instance, is accounted for by the fact that the thermostat had just shut off the gas *after* a period of burning, while the low reading of Feb. 19 evidently was not long *before* a similar period of burning.

There was nothing unusual about the ventilation of the house. Apparently, the window and door leakage plus the kitchen flue, gave about normal air change, for the occupants of the house testify to a feeling of freshness, and sling psychrometer observations made frequently indicate that it was never dryer than 40 per cent relative humidity.

Frequent observations with a thermometer at first story floor and ceiling lines indicated a temperature difference not exceeding 4 deg. Ordinary houses generally show a much greater difference.

In an office on the eleventh story of a Chicago skyscraper repeated observations show floor 60 deg., breathing line 70 deg. and ceiling 80 deg.

An interesting side light with this particular automatic gas fired hot-water boiler as compared with oil fired hot-water boilers, is the facility with which the number of burners in use can be increased or decreased arbitrarily in increments of 25 per cent. Many oil fired hot-water plants are difficult to control because the flame must be 100 per cent if it burns at all giving rapid intense flashes of heat and being limited as to regulation to length of time elapsing between flashes. For this reason, the most satisfactory oil fired hot-water plants have oil burners, the capacity of which is not greatly in excess of the normal requirement so that they must operate as nearly as possible in a continuous flame, eliminating the hot flashes.

The cost of gas up to April 1, 1926, amounted to about $163.00 with the heating season, based on averages, nearly over. Most plants in Chicago burned more fuel this year than normally. In any event it happens that the total cost for fuel was $181.00 less than that which the Gas Company estimated for ordinary construction, based on an extensive experience.

Gas bills ran as follows:

Sept. 26 to Oct. 28	$16.72
Oct. 28 to Nov. 25	27.67
Nov. 25 to Jan. 6	41.62
Jan. 6 to Feb. 2	27.52
Feb. 2 to Feb. 26	23.02
Feb. 26 to Mar. 30	26.77

The saving amounts to something like $527.00, made up of $347.00 in capital investment, and $180.00 in fuel, and in addition there has been the comfort and cleanliness of gas heating.

It is predicted that this house will be very cool and pleasant in hot weather, for experience with former less efficiently insulated houses is such that they say they "have to open the windows in hot weather in order to get the houses warm."

This is a plea for conservation of natural resources. Fuel is inevitably to increase in cost. It is the height of folly to waste an ounce of coal or oil or gas.

Everyone knows that ordinary construction methods the world over today, fail properly to balance maintenance and fuel cost against investment cost. Hollow spaces in walls and roofs such as between studs and rafters, allow little local air currents which pick the heat from one wall and carry it over to be lost on the other wall. Brick walls are notoriously porous and leaky. Plaster is simply an air filter. It is high time that these facts received more attention by owners and others in the construction field.

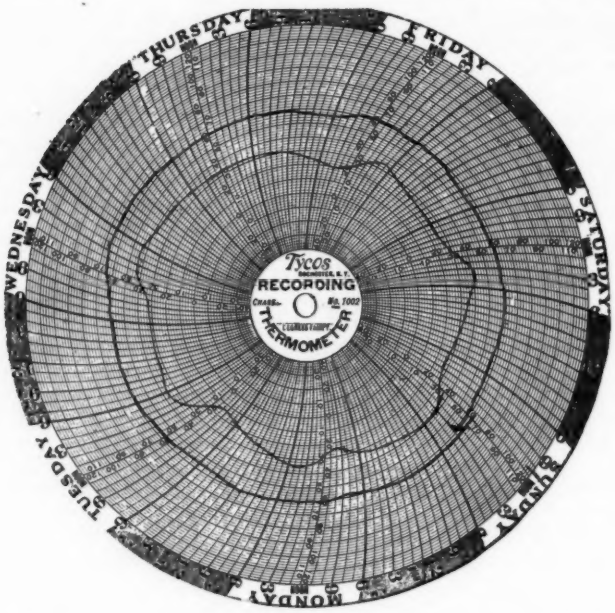


FIG. 6. CHART SHOWING OUTSIDE TEMPERATURE AND SECOND STORY TEMPERATURE FOR ONE WEEK

There are many other ways to insulate houses than the particular method used in this house. Cold storage, warehouses and ice boxes for years have been insulated in an effort to keep the heat outside.

The authors have tried, in this instance, simply to keep the heat *inside*. It is hoped that this example of a cheaply built wall which is nearly air-tight, and which in addition is a very good insulator, and which renders a wood skeleton nearly fireproof, may encourage better buildings.

DISCUSSION

H. S. ASHENHURST: I want you to know that I consider it quite an honor and a privilege to be able to stand on the floor before you this morning and present this matter.

In THE JOURNAL I noticed that the name at the head of the paper was H. S. Ashenhurst, non-member, and S. R. Lewis, member. I didn't think non-member sounded very well so this morning I handed in my application for membership.

Our object in this study is to find out what insulation really means. Here is a home in which constant temperature is maintained the same as in the laboratory.

If this Society would like to use that home for experimental purposes, I shall be very glad to have them use it at any time.

PROF. L. M. ARKLEY: I would like to ask Mr. Ashenhurst if he has made provision for double windows.

W. E. STARK: My justification for discussing this is that I am familiar with the heater used in this house and probably I can give some details which might be of interest. This is a type of boiler which has been designed for heating water for storage heaters and has four burners, each of which has a capacity of from 36 to 40 cu. ft. of gas per hour. This is based on 535 B.t.u. gas, which is the quality supplied in Chicago. The capacity of the heater is 60,400 B.t.u. per hour; based on an efficiency of 80 per cent which is readily obtainable. As this heater is generally used for heating water for storage tanks, it is also given a water heating rating, which would be about 70 gallons per hour at 100 deg. temperature rise.

The results of this installation show that it is possible to bring the many advantages of house heating with gas within the reach of the average house owner without burdening him with excessive initial installation costs. It might be interesting to compare the cost of this installation with the initial cost of installation of most oil burners of a size that would handle this residence.

This is a type of load that the gas companies are finding desirable in more and more cities. Many are establishing special heating rates as they have in Chicago, where the rate runs as low as 75 cents per thousand in some sections of that district. The gas companies are only too willing, I think, to cooperate with experiments of this kind because it is building up a load they have found desirable.

I would like to ask Mr. Ashenhurst whether or not the thermostat was of the clock type, set to cut down the temperature at night to 60 or 65 deg.; and whether any observations were made to determine whether any saving is realized from cutting down the temperature at night.

F. J. MCMORRAN: I would like to ask Mr. Ashenhurst if any difficulty was experienced due to the studding taking up moisture from the insulation.

J. F. MCINTIRE: If these comparisons are made upon the radiation, it seems to me that a paper of this kind should show the amount of radiation that would be required by some accepted rule for figuring radiation rather than by taking some unknown authority.

We have here comparisons made on estimated costs, which hardly could be taken into consideration. I would like to ask if the shrinkage of the wood would not reduce the efficiency next year over the results shown during the past year, and whether or not the floors are insulated, whether it would be justified to have insulation between the basement and the first floor?

The speaker made the statement that April 1 represented 96 per cent of the heating season in Chicago. I would be interested in knowing how he arrives at 96 per cent of the heating season.

A comparison was made by slide with the heating plant that was entirely inadequate for the job for which it was intended. I don't think that that is conclusive evidence. I make these remarks in the nature of criticism on their face; as a matter of fact, I am very much interested in this insulation, and think that it is a step in the right direction, that we have got to come to better insulating of houses in this country to get satisfactory heating.

S. R. LEWIS: I was one of the parties who checked the heat losses on the basis

of uninsulated walls, using my standard office practice for public buildings, which carries an allowance of 30 per cent of the wall and window loss for leakage, and which uses a variable factor for wind and exposure, beginning with 30 per cent on the North.

The method of insulation is especially interesting to me because unlike any of the conventional insulators which are applied in sheet or slab form, it fills solid the hollow wall spaces, preventing the internal air circulation which carries the heat so rapidly from the warm inside to the cold. It also promotes slow burning, tending toward fireproof construction and eliminates rats and mice.

I was taught by an old steam fitter, many years ago, that if I wished to fasten anything into a hole in a brick wall I should set it in plaster of paris, as that was the only available cement which *expanded* on setting instead of shrinking on setting. This Insulex is plaster of paris, and I presume it expands, leaving no open joints against the studs.

HOMER R. LINN: I made the original heating plan by which the radiation was installed in Mr. Ashenhurst's house. I used the constants that are published in the Ideal Heating Practice but modified these constants as directed by Mr. Ashenhurst, to make them comply with the heat loss of the insulating material which he was using.

When I took into account the effect of his insulating material, it had such an influence on the radiation that I wrote Mr. Ashenhurst a letter and told him I would not guarantee that the amount of radiation I was going to recommend him to install would heat the building, because I felt he had the wrong heat loss constant for Insulex. I do think it is timely to consider the different kinds of insulation. The Western New York Chapter in Buffalo was having a discussion when I was there last March and I was quite surprised to hear the statement that the insulating effect per dollar of cost was less for Insulex than it was for cork.

F. D. MENSING: I think the figures were all high. I think we all know today what the effect of this building material is. It is obvious.

H. M. NOBIS: I want to ask about the humidity—was washing done in the basement?

H. R. LINN: I want to say that after I got all of this radiation figured it looked so small that I added 10 per cent to the amount called for in accordance with Mr. Ashenhurst's heat loss constant for his insulating material. I have never before told him I did this and I think this is one reason why there is too much radiation in this house at present.

A. A. BLOMFELDT: What is the condition of the atmosphere? What is the relation of the CO_2 content?

H. S. ASHENHURST: One thing I neglected to mention in my paper was that storm windows were put on the house. I talked to Professor Willard on that and he suggested I use felt on the windows so I could get the benefit of fuel saving, but not knowing how much air I was going to use in the house they were put in rather loose. Those were put on the middle of December, and by reference to the gas bills apparently there wasn't much fuel saving, but a great difference in comfort when you get near the windows.

The Peerless type of radiator was used in the sun parlor and kitchen, and in the balance of the house the Corto type. The gas in Chicago is 75 cents a thousand feet. That only has a B.t.u. content of about 535 whereas your West Virginia natural gas runs close to 1000. I am not sure about that; that is my impression.

The cost of gas for household use in Chicago, not for heating, is $1.00 per 1000 ft., and you see we were using the Lovekin heater for heating the domestic hot-water heater; then the garbage incinerator and the range, so the cost of domestic gas in Chicago is ten dollars a month. It averages from one month to another about $10.00 a month. Gas is higher in Chicago than in places where you have natural gas because the cost per thousand is more and the B.t.u. content is much less.

In regard to the thermostat: it was a Jewel clock type, and it was arranged so at night the gas could be turned down and come on in the morning. The People's Gas Co. asked me for some records so it could be determined whether it was cheaper to leave the gas on at a point to make 70 deg. during the day and night, or cut it down to 60 during the night. This last chart I showed was made on one week to determine that. The week before, the house dropped to sixty at night. I spoke to Mr. Johns about that and asked if he would please get those computations for me, because I have been asked for them. Figuring briefly, it struck me it cost 75 cents more for the week when the house was kept at 70 than when it dropped at night. Frankly, I don't know which is better. The trouble with keeping the house warm at night is that it is uncomfortable in the bedrooms. When it is allowed to drop to sixty, it is more comfortable in the bed rooms, and there is no use in keeping the rest of the house heated if you are not occupying it.

The question has been asked about the studding shrinkage. The best thing I can tell you about that is in the house, in the upper closet, some of the wall finish was left off and was left off in the upper rafters. There was quite a big space there. I have examined that and so far there is no shrinkage. I can't tell you whether any will take place. Insulex weighs 12 pounds per cubic foot. It isn't the same as putting in a wet mixture where you would have a greater density. It dries out quickly and so the studding itself getting wet would not be inclined to shrinkage, although the natural shrinkage of the wood might come later.

My opinion would be (although I rather hate to express opinions) that if any shrinkage did take place, it would probably be the thickness of a paper and that your B.t.u. transmission would only be affected through that small amount, although I am not positive about that. I am always willing to acknowledge there are a lot of things I don't know. There are some things I do know, and some I don't. That stud proposition so far has shown no effects in the house.

The floor insulation in the lower floor was put in with this purpose in view. Mr. Linn spoke to me about that. He said, "I believe it would be advisable to insulate that floor so that you do not have to keep your basement warm." So the floor was insulated to a depth of two inches, and to start in with, the pipes in the basement were not covered. I kept a record of the temperatures in the basement every day, and they ran 68 deg. I then covered the pipes. The temperature dropped to 62 deg. Now, the temperature of the floor above was 68 deg., which was only 6 deg. difference, so I doubt from an insulation standpoint that that is absolutely necessary, although I found it had this effect: we use our basement as the playroom for the children and you can hear no noise on the first floor when any one is playing in the basement; so I believe to cut out the ordinary basement noises and make more quietness in the house, the floor insulation pays; and it pays in this other way: that you put a fire stop over the entire lower floor, and with that and your space filled between the studs, from the foundations up, you have really at low cost practically what we call fireproof construction.

The question was asked about 96 per cent of the heating season. Those figures are gotten from the Gas Company in Chicago, who have so many degree days, and they have taken their estimates year after year, and they found out that nor-

mal heating season in Chicago is so many degrees of heat. This year, the season started very early. We have a certain percentage each month to figure up. This year we burned a great deal of gas in October, and our heating season was quite long, so on their estimate of a normal season, taking the weather record, I understand, for fifty years, the heating season in Chicago is 96 per cent over the first of April, the normal heating season, and on the 7th of April one hundred per cent. Of course, that may be a theoretical proposition, but is based on the averages given by the People's Gas Company from whom I take my authority.

Somebody asked about the washing in the basement. We have been sending our washing out, so that didn't enter into the case.

Someone asked about the CO_2 content in the house. That question has been discussed a great deal, and I thought some time of taking samples of the air and having them tested by some engineering institute in comparison with air in other houses. The only thing I can say for that is that the house always felt good, and you always felt comfortable in it. People would come from the outside and remark on the extreme comfort and how much better they felt in that house than in the average house. Of course, the freeness from drafts, the fact that your feet are never cold, had something to do with that, but to be frank with you, I can't answer your question. We did have a flue in the kitchen which went through the roof, so we couldn't close it. The flues in the basement were not closed so air came through them, so for some reason, the house seemed to be unusually well ventilated, and you always felt good when you were in the house. I think sometime I might analyze the air, but this is the best I can tell you on that at present.

H. M. HART: I would like to ask if the windows were opened in the sleeping rooms at night.

H. S. ASHENHURST: The windows were opened in the sleeping rooms the same as they are opened in other houses where we lived.

M. C. W. TOMLINSON (WRITTEN): This paper is very timely and would be much more interesting to members if Messrs. Ashenhurst and Lewis had noted the unit cost for gas and the particular type of radiator which was used.

Gas fuel has an advantage seldom appreciated by the public. The maximum demand of the heating season is often not more than one day in duration. The average demand in this country varies from 25 to 35 per cent of the maximum requirement. The heating season covers a period of from 6 to 8 months. With thermostatic control similar to that used in the experiment described and with three or four burners under this control it is possible to secure considerable economy in gas consumption and a fair degree of comfort.

During the winter of 1921–22, I heated a large 9-room frame house, occupied by two families, with West Virginia gas at 50 cents per 1000 cu. ft. The heating system was of the warm air type but was not particularly efficient. The total cost for the season was $100.00 and included gas used for cooking and hot water heating. This property was located in Ohio and was about 20 years old. The cracks around doors and windows were quite large, no storm windows were employed but the thermostat was set every evening to give a temperature of 50 deg. fahr. during the night and 70 deg. fahr. during the day on the first floor. This information may be interesting but is meagre and thus cannot be used for comparison with the data submitted.

It would be interesting to know if the total cost for heating the Chicago home included gas used for cooking and for heating water.

No. 747

HUMID AIR AS A HEATING MEDIUM

By FOSKETT BROWN, NASHVILLE, TENNESSEE

MEMBER

THE advantages of heating with a low temperature medium have long been recognized, not only because of the great economy, but for reason of the greater ease of regulating the supply of heat to meet the requirements of varying temperature conditions.

Hot water has long been a favorite medium, due particularly to its adaptability for use at low temperatures. Because apparatus adapted for its use is often heavy, bulky and expensive, some people are not in favor of it and the lag both in heating up and cooling down, due to the large amount of water in the system, makes it undesirable where quick changes of temperature are required. This condition is particularly noted in the South, where the outside temperature may be quite low in the early hours of the day, with great rise in temperature in a few hours.

The vacuum system of heating held promise of making possible the use of steam at pressures below the atmosphere, and therefore at lower temperatures than with steam at or above atmospheric pressures. Apparatus for obtaining a vacuum within the radiator is expensive in first cost and maintenance, and is, therefore, suitable only for large plants where labor is employed and trained to use such equipment. Then too, ordinary practice in the use of the vacuum system utilizes a partial vacuum within the radiator to promote the rapid filling of the radiator with steam, which, however, when filled is approximately at atmospheric pressure, and the temperature 210 to 215 deg. fahr. A vacuum in the return lines promotes a rapid discharge of air from the radiators as it accumulates, and assures a positive return of water of condensation to the plant. In other words, the mechanical vacuum system is primarily a system for promoting the positive circulation of steam and the return water of condensation, and does not in general utilize materially low temperatures within the radiators, the temperature being approximately the same as in the average low pressure gravity or vapor systems.

The so-called modulation or vapor systems have been largely used with various forms of throttling or restricted opening admission valves for regulating the flow of low pressure steam or vapor to the radiator at atmospheric pressure, but the steam so admitted has the temperature 212 deg. fahr. corresponding to its pressure. Whether the radiator be completely or partially filled, the radiating surface with which the steam is in contact will approximate the temperature of the steam.

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While it is possible by a careful and partial manipulation of the admission valve of the type described, to regulate the steam supply to the radiator so as to furnish a small amount of heat to meet mild weather conditions, such a radiator will be heated to approximately the full temperature of the steam for a portion of its surface, the remainder of it being cold and inactive, and the distribution of heat in the radiator lacking uniformity. Such a method is not as satisfactory or economical as if the heat were distributed uniformly over the entire heating surface, as in hot water radiation, where it is possible by regulating the water flow to produce a low temperature in the radiator and maintain approximate uniformity of temperature throughout.

Heating engineers have experimented for many years with a view to the development of a system of heating that would combine the quick action and flexibility of steam with the mildness and economy of hot water. It has been their desire to accomplish this with the standard forms of radiators and heating equipment, and with inexpensive and simple apparatus that would present no operating difficulties, even to the inexperienced. The primary object of this development is economy, and the secondary, no less important, is the attainment of a more comfortable heat, or ultimately, a lesser temperature differential in the heated room between floor and ceiling, producing the desired knee height comfort, referred to by Dr. Brabbée in his recent paper on The Heating Effect of Radiators.

Taking first the economic reason for such a development, it is well known that with present methods of control and operation rooms are overheated so that much heat is obviously wasted, particularly in mild weather. With present forms of radiator admission valves, control of the heat input to a radiator is difficult, unless the boiler pressure is very accurately held to a fixed operating point. This is quite difficult, on low pressures particularly, and especially so if soft coal is the fuel. On anthracite, or oil fuel, there is less fluctuation, and even with these fuels considerable difficulty is experienced. With present methods the heat input to a radiator may be controlled within pressure limits but as pressure increases the control is lost, and the radiator is heated to full steam temperature. For example, a room from which the heat loss in the early hours of a Spring day is 12,000 B.t.u., equipped with a radiator of 12,000 B.t.u. output capacity at 215 deg. fahr. and 70 deg. fahr. room temperature, should be heated full radiator capacity during the warming up period. Assume now that as the outside temperature rises, the heat loss from this room is diminished to 6000 B.t.u. per hour. For economical operation, the radiator input should be halved. Due to the difficulty of accomplishing the reduction of radiator input it is noted generally that the heat loss from the room will be increased, by opening windows, or the radiator will be shut off entirely, neither method accomplishing the desired uniform heat with economy. Therefore, the development of a method which will permit the control of B.t.u. input to the radiator at the will of the room occupant is most desirable. A system which will permit the operation at any percentage of its capacity is the aim of the development for fuel conservation and economy. The ultimate, then, is the development of a method of metering to the individual radiator sufficient heat to supply the demand of heat loss from the room.

The second principle involved the comfortable heating of the room with small temperature differential between floor and ceiling, and a comfortable knee height temperature is no less important than economy of operation. It is known that the air column rising above hot water radiators heated to 170 deg. fahr. is more thoroughly diffused, and more mildly and comfortably tempered, and the resulting room temperature more comfortable than is possible with the fast rising column

passing over the radiator surface heated to the temperature of the steam. From this it is evident that if it is possible to heat a radiator with steam to 170 deg. fahr., that the desired low temperature differential between floor and ceiling will be attained accomplishing the comfortable and desirable knee height temperature, or combining the mildness and economy of hot water heat, with the quick action and flexibility of steam. In the early morning hours it is essential to heat the room rapidly. This can be accomplished if the radiator is heated to 190 deg. fahr., or in severe weather to full steam temperature if desired, cutting down the radiator temperature, and bringing the room to comfortable heat after the chill is overcome. This calls for a definite control of radiator temperature, and a wide range of possible temperatures attainable in the radiator.

This problem has been solved as follows: As is well known, air in intimate contact with water absorbs it, and tends to become saturated with water vapor, and the higher the temperature of the air, the more moisture will be absorbed. This moisture does not exist as entrained water, but has actually been evaporated

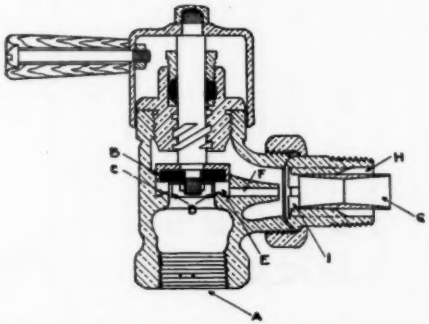


FIG. 1. SECTION OF DEVICE FOR MECHANICALLY MIXING STEAM AND AIR IN RADIATOR

into vapor or steam, and as such has heat of vaporization or latent heat. This latent heat can be imparted to colder surfaces by condensation of the vapor, and it is evident, therefore, that saturated or moist air, humid air, would be suitable as a medium for heating with the ordinary forms of radiating surface, if proper provision were made to replenish the supply of vapor as it condenses. Such a medium could be maintained at any desired temperature, and if so maintained would have all of the desirable characteristics of water as a heating medium with the added flexibility of steam, of heating and cooling quickly.

Steam, when allowed to flow into a chamber containing air, tends to rise to the top of the chamber, due to its lower density, and will have the temperature corresponding to its pressure. This condition may be noted in a radiator of the hot water type. When steam is admitted with the ordinary type of admission valve it will heat the radiator to approximately its own temperature. If the pressure is well controlled, and the valve partially opened it will heat the radiator along the top of its loops while the lower portion remains cold. If, however, the contents of the radiator or chamber are agitated mechanically so as to mix intimately the steam and the air, the steam will be absorbed by the air forming a humid mixture or saturated air at a lower temperature than that of the steam, and the mixture so

formed will serve as a heating medium, the vapor or steam carried, condensing on the surface of the chamber or radiator. If steam is admitted as fast as the condensation occurs, the temperature of the humid mixture will remain constant. If more steam is admitted, the temperature will rise until a balanced condition is reached where increased heat losses due to radiation equal the heat furnished by the incoming steam. Likewise if the steam admission is restricted, the temperature will drop. By this process it is possible to obtain any desired temperature of the humid mixture from that of the original air content of the radiator, to that of the inflowing steam itself.

It is evident that this process can be performed in the ordinary type of hot water radiator, or similar vessel, furnishing a suitable circuit for the circulation of the humid mixture by means of a propeller or fan, or other means, within the radiator,

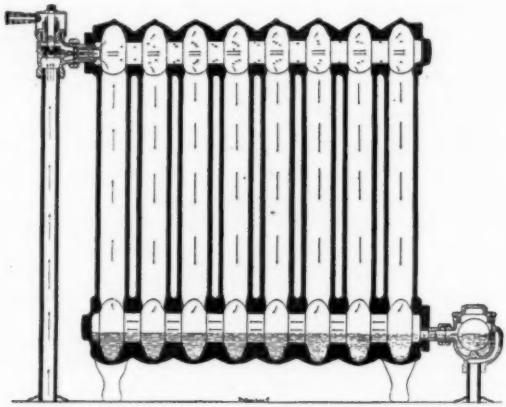


FIG. 2. STANDARD HOT WATER TYPE RADIATOR EQUIPPED WITH DEVICE FOR MIXING STEAM AND AIR

operated by a motor or otherwise, the steam being admitted at any suitable point through an orifice of variable size, or a regulating valve.

It is known, that steam even under very light pressure will generate a high velocity when dropping to a lower pressure, and when properly directed in the form of a jet forms a very powerful and effective mixing and circulating device, and will, while furnishing the necessary heat supply to maintain the required temperature of the humid mixture, also serve to generate and circulate the humid mixture so as to maintain a satisfactory uniformity of temperature throughout the radiator so constructed as to permit the circulation of its contents, as is the conventional hot water type radiator.

The new apparatus is designed to perform the functions described of admitting and regulating the steam supply to a radiator of the conventional hot water type, and, by the action of a jet of steam at high velocity through a venturi tube to cause a generation of the humid mixture, and its effective circulation throughout the radiator, as well as a definite control of the temperature of the humid mixture. This apparatus provides a method of mechanically generating and circulating a humid mixture within the radiator, and controlling the temperature of the humid

mixture, at any desired temperature, from that of the original air content of the radiator, to that of the steam itself.

The device is designed to provide a method of heating by steam, by which, with steam at any pressure, radiators or similar vessels may be uniformly heated over their entire surface to any desired temperature from that of the original air

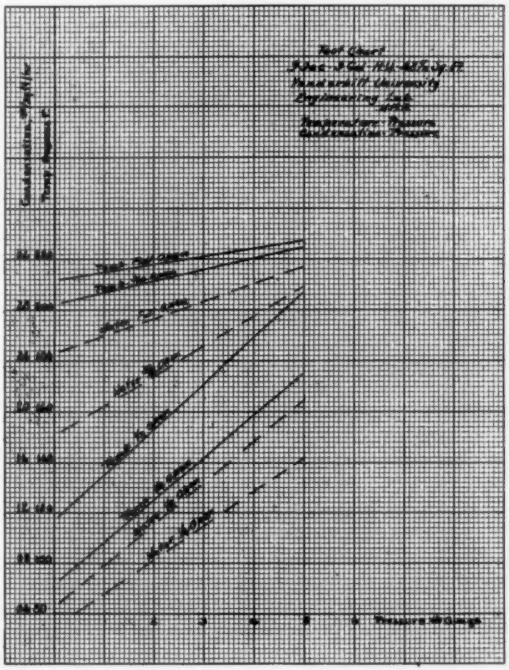
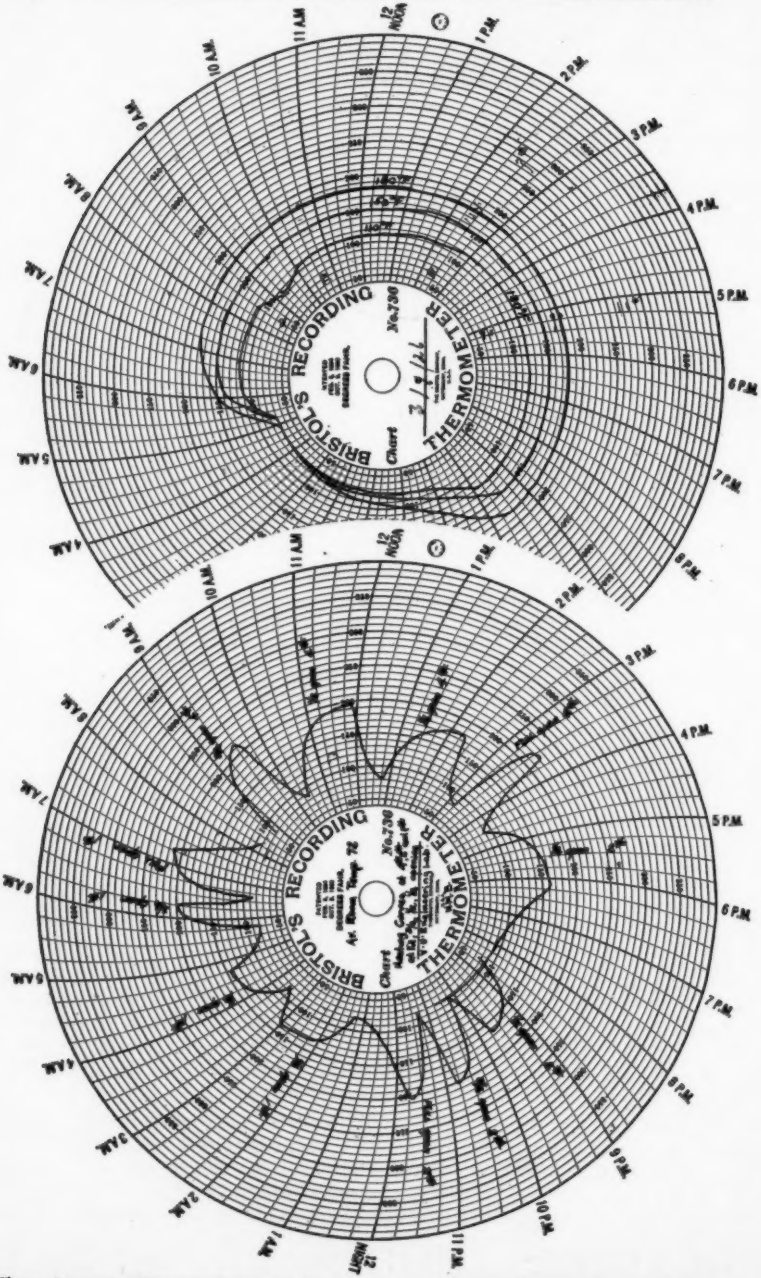


FIG. 3. CHART OF TESTS ON NINE-SECTION THREE COLUMN RADIATOR

content, to that of the steam itself. In the device is incorporated all of the apparatus necessary for the accomplishment of this purpose.

Summing up briefly, the new method of heating with humid air as a heating medium consists of the mechanical mixing of air and steam in the radiator, so as to form a humid mixture, in which the heating medium is the steam or vapor carried by the air, the continuous circulation of the humid mixture within the radiator, and the maintenance of the desired temperature, or variation of this temperature by the metering of the steam admitted.

Mechanically, the device is of the standard design and dimensions of the conventional radiator admission valve, operating in exactly the same manner, differing only in the metering effect obtained. With it is effected the uniform warming of a radiator on mild days, its uniform heating on colder days, and a very definite control of the temperature of the radiator at the will of the room occupant. That



FIGS. 4 AND 5. CHARTS SHOWING OPERATION AT VARIOUS TEMPERATURES AND VALVE OPENINGS AND RAPIDITY OF HEATING

is, the temperature input to the radiator may be definitely controlled to meet the requirements of the weather for temperature output of the radiator. Thus is accomplished, *First*, economy of operation, and *Second*, the ultimate room comfort desired.

Fig. 1 shows a section of the device, and Fig. 2 a section of a standard three-column hot water type radiator equipped with it and a standard trap. These indicate the simplicity of construction and operation of the device as well as its function.

Referring to the section of the valve shown in Fig. 1, steam is admitted at point *A*. When it is closed, the conventional valve disc *B* is closed against seat *C*, preventing the passage of steam to the radiator. As the handle is rotated counter clockwise the disc and metering slot sleeve *D* lifts vertically the area of the metering slot, a narrow slot in thin tubing increasing proportionally to the distance lifted. As the disc leaves the seat, steam is free to pass through the metering slot, into the annular jet chamber *E*, and thence to and through the jet *F* at high velocity. Leaving the jet the steam passes through the mixing chamber *I*, where the air within the radiator is intimately mechanically mixed with it, and through the venturi tube *G*, and thence into the radiator at a velocity sufficient to circulate mechanically the humid mixture within the radiator. The passage of the jetted steam at high velocity through the mixing chamber and venturi tube accomplishes an induced draft of air or vapor from the radiator, through the annular space *H* between the spud and the venturi tube, into the mixing chamber, where it is remixed with the steam supplied. It will be seen that the accurate control of the area of opening of the metering slot is effectually a variable area orifice, and when the output demand is small, a small opening of the valve will deliver the necessary temperature input, and likewise, as output demand increases, a larger opening will give the greater input necessary.

In the radiator section, Fig. 2, equipped with this valve, there is shown diagrammatically the action of the humid mixture within the circuit, the valve being shown four eighths open. Full opening is accomplished on seven eighths turn of the handle. The first four eighths are utilized for metering through the metering slots and the last three eighths for full opening when input demand calls for heating the radiator to the full temperature of the steam. It is observed that the jet of humid air leaving the venturi tube does not expand until it has passed through the first nipple of the radiator, and consequently, that the first loop is utilized for the induced flow of the humid mixture, from the lower portion of the radiator upward, and into the mixing chamber. There is a downward travel of the humid mixture in each succeeding loop and a reverse travel across the bottom connection of the radiator, accomplishing a thorough circulation, and corresponding uniformity of temperature. Even when full open, part of the steam, diverted through the jet, serves to circulate the steam throughout the circuit, improving the heating effect, as it is well known that the passage of a heating medium over a radiating surface is more efficient than the same medium lying inert against that surface.

It is to be noted in the section, Fig. 2, that the valve is delivering to the radiator, at high velocity, make up steam in the form of a jet, the action of which mechanically generates the humid mixture of required temperature within the radiator, and mechanically circulates the humid mixture within the radiator providing in this manner a method of heating by steam, by which, with steam at any temperature and pressure, radiators or similar vessels may be uniformly heated over their entire surface to any specified temperature, from that of the

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original air content of the radiator, to the temperature of the steam corresponding to its pressure, and in this manner accomplishing by a definite control of the steam consumption, the first principle, economy, and by a definite control of the steam input, and the circulation, the uniformity of temperature, below steam temperatures which result in the accomplishment of the more comfortable heating of the room.

Results Charted

In Fig. 3 there is shown a composite chart of tests on a nine-section three-column 32 in. hot water type radiator, 42.5 sq. ft. radiating surface. The temperature curves are plotted against pounds pressure and degrees fahr., and the condensation curves against pounds pressure and pounds of water condensed per square feet per hour. The temperatures are averaged from five thermometers, placed at representative points within the radiator loops, and checked by a recording thermometer at the top of the last loop. The pressures were recorded from a mercury column, and controlled from the main line through a reducing valve, and were consistently constant. The condensation was discharged through a trap and weighed. Observe that the curve for full opening follows the pressure temperature curve, the curve for three-fourths opening drops slightly under this and also note the control of the temperature effected with valve one-half open. At $^1/_2$ lb. pressure the temperature is 124 deg. fahr., and at 4 lb. it is 188 deg. fahr. The slope of this curve and that for one-quarter opening readily demonstrate the facility of temperature control in the radiator. These results are checked again by the water condensed. On the water curve for one-half opening of the valve, at 1 lb. pressure, observe that the condensation rate is 0.08 lb. per sq. ft. per hr., approximately one quarter capacity.

In this connection it is interesting to see that a radiator operating at 150 deg. fahr., from tables on page 40, AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS GUIDE, is operating at approximately one-half capacity. Also, that to secure this temperature with a vacuum system it would be necessary to operate at 23.4 in. vacuum. The charts from the recording thermometer show the operation at 120 deg., 150 deg. and 180 deg. fahr. for periods of 15 hrs., room temperature 72 deg. fahr., with various valve openings. The second chart shows the rapidity of heating, the radiator being cooled by an air blast.

This test data gives a very comprehensive idea of the definite control of the radiator temperature, the uniformity of the radiator temperature, and it is readily seen with this system, how both the economical operation, and the comfortable heating of the room can be accomplished.

Actual installations, where other systems have been compared to the new system, by a metering of all condensation, show that the average saving in fuel exceeds 25 per cent. The comparative temperatures of the rooms are also more uniform, and do not show the wide range of temperature variation shown by the older systems.

Accomplishments of Humid Air as a Heating Medium

From the data given, it can be seen how humid air as a heating medium accomplishes the primary object of development, economy of operation, by reducing the steam consumption, for comfortable heat, and the secondary object, lesser temperature differential between floor and ceiling temperatures, or a comfortable knee height temperature, by operation of the radiator at temperatures lower than

is possible in the conventional steam installation. In this way the combination of the quick action and flexibility of steam, with the mildness and economy of hot water is accomplished with standard forms of heating equipment, and with simple and inexpensive apparatus, which presents no operating difficulties, even to the inexperienced.

DISCUSSION

C. F. EVELETH: There are a number of valves used today known to the trade as modulation valves which will accomplish the same results as that described in the paper. I have in mind one particular type which employs a plug having a special taper, to restrict the area of opening through which the steam passes. The difference seems to be in the method of securing modulation.

It is not quite clear to me from the speaker's paper how he gets rid of the air within the radiator. Up to a certain point, I can understand how, by the proper control of the opening in the valve, it mixes up the entering steam, with the air which is present in the radiator. When you want to have complete heating efficiency, in other words, when you want to get the maximum heat from the radiator, it is necessary to expel all the air and fill it completely with steam. If you can't do that, then you must have a larger size radiator to obtain the same heating effect, since the temperature of the mixture of steam and air is lower than steam alone, at the same pressure.

I am wondering how the valve can be used in connection with a vacuum system. I can see where it may be used with a modulation or open return line system but when a vacuum pump is attached to the system, what is to prevent the air passing out of the radiator into the return pipe?

The statement made that there is less economy where the distribution of heat in the radiator is not uniform than there is where the heat is distributed, is not quite clear to me.

R. V. FROST: Mr. Brown sent one of his valves to me to test, and as I was curious to know the comparative performance of this with the usual type of fractional valve, I arranged a test after the following manner:

The valve was connected to a 45 sq. ft. wall radiator as shown in the illustration, Fig. 1a. The return end of the radiator was given a free opening, the air being allowed to escape through an open pet cock as shown.

Thermocouples of No. 14 iron-constantan wire were connected at the four corners of the radiator with common boiler cement, the points of connection being plainly visible.

The surface temperatures at the four thermocouple points were the principal determinations, although condensation was also measured.

The first test was to determine the capacity of the valve, or the action of the steam in the radiator when the valve is turned to a full opening, with a cold radiator. The results of this test are shown on Fig. 2a.

Note the relative rapidity at which the four points heated, as shown by the four temperature lines, and then note the relative position of the temperature lines after the radiator had become fully heated. Contrary to expectation, points (1) and (2) were the coolest. This can be attributed to the recirculation of air due to the jet action of the valve. Owing to thermocouple point (1) being located close

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to the valve, the steam had not expanded to fill the full passage in the radiator, thus resulting in a layer of cooler air being in contact with the metal.

For the second test, the valve was closed from a full opening to one-sixth opening, and the radiator was allowed to cool to normal temperature, the result being shown in Fig. 3a. In this case the temperature lines show that the extreme temperature variation from the hottest to the coolest point is 60 deg., that the top of the radiator has a mean temperature of about 135 deg., and that the difference between the

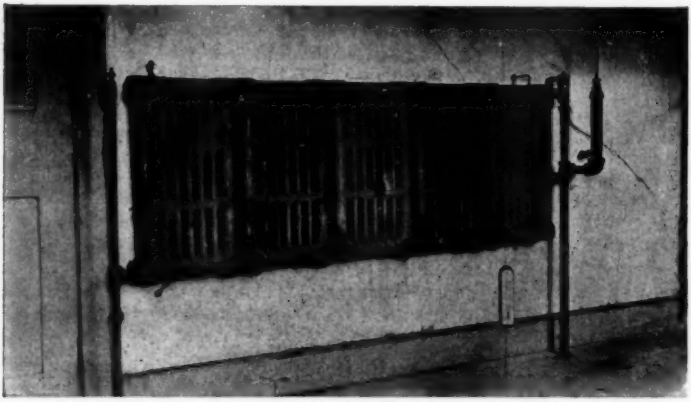

FIG. 1a. WALL RADIATOR USED IN TESTING VALVE

mean of the top of the radiator and the bottom is but 45 deg. In considering this temperature effect it is to be observed that the air could readily re-enter the radiator through the open pet cock, thus preventing possible forming of vacuum in the radiator.

Comparative Tests

In order to compare this valve with a standard type fractional valve, such a valve was installed in place of the Brown valve, and the valve set at different fractional openings.

With the valve wide open, after a three-hour run, which insured stabilized conditions, the temperature readings at the four points were as follows:

No. 1	216 deg.
2	212
3	213
4	210

It is to be noted in this case that the inlet showed practically steam temperature, 216 deg., and that the other points approached atmospheric temperature, showing that the steam pressure in the greater portion of the radiator was close to atmospheric pressure, this of course being due to the open pet cock on the return.

The condensation in this test ran about 95 per cent of the maximum capacity of the radiator.

With the valve set at one-fourth opening, the surface temperature dropped to the following:

No. 1	212 deg.
2	210
3	202
4	140

while the condensation amounted to 72 per cent of the maximum.

With the valve set at the smallest fractional opening that it was possible to set and still maintain a steady flow of steam, the temperature reached:

No. 1	203 deg.
2	98
3	160
4	98

while the condensation ran 11.5 per cent of the maximum.

Final Test Results

This last test is almost a parallel performance with the test shown on chart, Fig. 3a, for the condensation for the two tests is about equal. With this valve there is an extreme temperature differential of 105 deg., as compared to 60 deg. on the Brown valve, while the mean temperature of the top is 180 deg. as against 135 deg., and the mean difference between the top and the bottom of the radiator is 80 deg. against 45 deg.

Owing to the fractional valve that was tested being designed for pressure of two to four ounces, instead of the 1 lb. pressure used, fractional control was much more difficult than on the Brown valve which is designed for 1 lb. pressure. For this reason the experience in these tests in this one particular are not representative of the fractional valve.

I have but one criticism to make of Mr. Brown's paper, and that is his statement that this valve is more economical in operation than the usual type of fractional valve. With our present methods of testing radiators, we are unable to determine with a positive degree of assurance the percentage of efficiency. Consequently Mr. Brown would be unable to produce acceptable evidence to support his statement for increased economy.

M. C. W. TOMLINSON: I would like to ask Mr. Frost what the diameter of the wire was; what kind of thermocouple was used, and also how the hot end of the thermocouple was installed on the surface of the radiator.

R. V. FROST: The diameter was $^1/_8$ in. wire. It was cemented to the radiator with ordinary Portland cement. One reason why I showed the first slide was to show there was practically no lag in the thermocouple because the steam temperature began to go up immediately the valve was opened and all four thermocouples acted in about the same relationship. Of course, there is probably some lag there. Also in testing the fractional valve, I got the same at the inlet as the steam.

M. C. W. TOMLINSON: I asked because it is a well-known fact that the smaller the size of the thermocouple wire, the less the thermocouple reading is affected by radiant heat. In other words, to get the true temperature of convection the bead of the thermocouple should be as small as is practicable.

FOSKETT BROWN: I will answer Mr. Eveleth's questions first. He asks how the

XUM

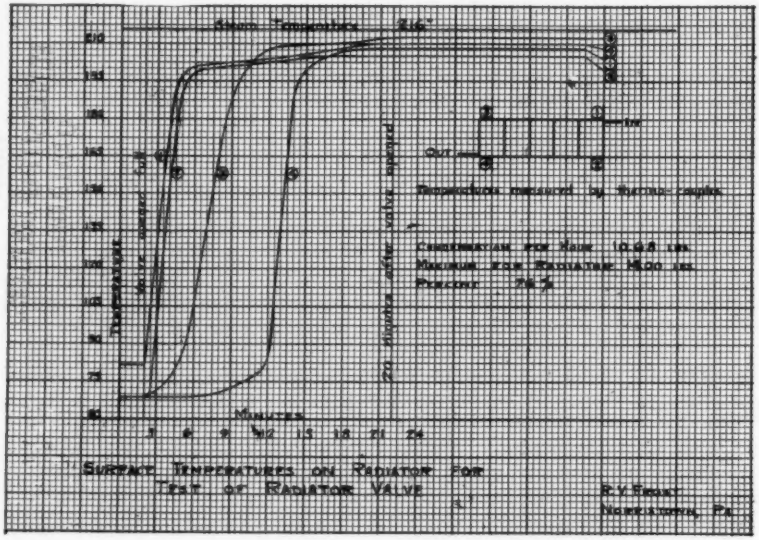

FIG. 2a. RESULTS OF TEST WITH VALVE WIDE OPEN

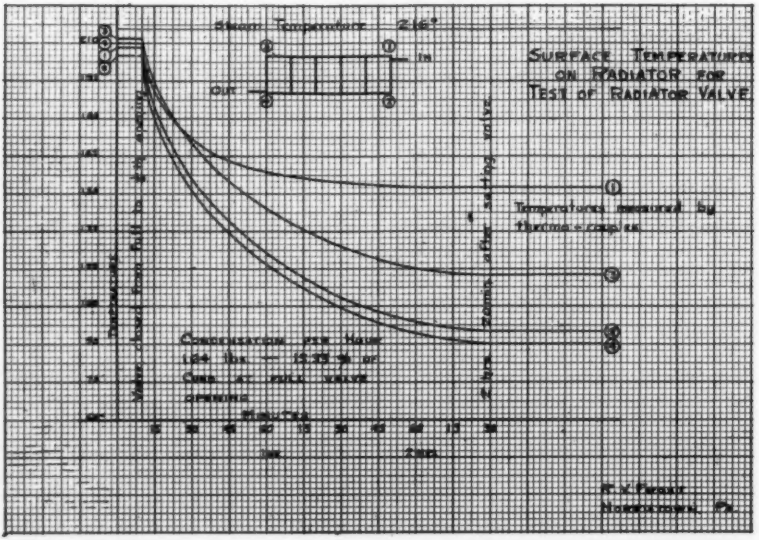
Steam Temperature 216°
Surface Temperatures on Radiator for Test of Radiator Valve
Temperatures measured by thermo-couples
Condensation per hour 164 lbs. — 16.25% of Cond. at full valve opening
Minutes
R. V. Fraser
Norristown, Pa.

FIG. 3a. RESULTS OF TEST WITH VALVE ONE-SIXTH OPEN

radiator is freed of air. Examination of the valve will show that it may be opened completely, just as any other inlet valve, and that when so opened, all air will be forced out of the radiator, and the radiator heated to the full temperature of the steam. In other words, when it is desirable to heat the radiator full hot, we force all air out, filling the radiator completely with steam.

The second question was with regard to the loss of air due to the pull of a vacuum. If a thermostatic trap is used on the radiator, it will remain open except when the radiator is operating at steam temperatures. In such a case, when the radiator is operating at a low temperature, say 150 deg. fahr., with 1 lb. pressure at the valve, and 4 in. vacuum on the return lines, the radiator will have approximately 4 in. of vacuum, and the effectual operating pressure at the valve will be 3 lb. That is, the vacuum pull will be added to the pressure push, at the valve. It is preferable to use a mechanical trap, which operates as effectively at 150 deg. as at 212 deg. In any case, a partial vacuum within the radiator acts to increase the operating pressure at the valve, and unless we pull a perfect vacuum on the radiator, we will always have some air within the radiator unless we force it out with addition of steam. A partial vacuum within the radiator simply rarifies the contents of the radiator, decreasing slightly the air carrier for the vapor, and in no way reducing the effectiveness of the new system. It is quite possible that the vacuum in the radiator may be greater than the vacuum in the return lines, when the valve is in the controlled position, with the sleeve in the port, and the variable orifice in action.

Effective Heating with Low Temperature Surface

Mr. Eveleth asked why it is more economical to heat a room with a radiator heated uniformly to a low temperature, than with a radiator heated partially steam hot, or stratified. This is an interesting question, and my answer is that actual tests, where condensation from both types of systems was actually weighed, showed that the humid air system used considerably less steam. This fact is attributable to two features, *First*, the feature of increasing the efficiency of the radiating surface by circulating its contents, and *Second*, to the fact that a room heated by a low temperature surface will have a more uniform and comfortable temperature with a lower temperature at the ceiling, and higher temperature at the floor, than when heated with a partially steam hot radiator. With the latter, the ceiling temperature will be quite high, as compared to the breathing line temperature, and the heat loss from the room correspondingly greater, requiring more input to maintain the breathing line temperature, and consequently more steam.

A. C. WILLARD (WRITTEN): The results you describe as obtained with your system are certainly remarkable, but I am very much in the dark on the manner in which you control the amount of air in the radiator. What kind of a return trap do you use and what vacuum, if any, is carried on the return lines? How do you keep the right amount of air in the radiator? Why doesn't the radiator lose its air at various times? Once a radiator loses its air, how do you replace the air? If the radiator is *always* full of air, how do you ever get it steam hot all over?

The operation of any heating plant with low temperature heating surfaces, es-

pecially in mild weather, is always desirable and should result in a smaller differential between floor and ceiling temperatures, than in the case of systems with high temperature heating surfaces. Your idea of average operating pressure at the inlet valve of one-pound gage pressure for all types of heating systems seems correct to me.

No. 748

SOME RESULTS OF HEAT TRANSMISSION RESEARCH

By F. B. ROWLEY,[1] MINNEAPOLIS, MINN.

MEMBER

THE purpose of this paper is not to present any new and startling discoveries in the field of heat transmission but rather to relate some of the progress which has been made at the University of Minnesota along generally accepted lines. The writer has long since come to the conclusion that results in research are obtained by persistent following of the fundamental laws rather than by spasmodic drives at some spectacular objective. About eight years ago the work of heat transmission through building material was started under the direction of the late John R. Allen who was then dean of the college of Engineering and Architecture. Some of the results obtained have been published from time to time in the A.S.H.&V.E. JOURNAL but a more complete record of the work done before June, 1924, is given in Bulletin No. 3 of the Engineering Experiment Station.

In the first series of tests the single wall hot box method was used but later the double or guarded box was designed and built. While very satisfactory results have been obtained with the double box, it must be admitted that the apparatus has short comings as compared to the hot plate. Some of these are the greater length of time required to adjust the temperature in the apparatus to get accurate results, the longer time and additional expense required in making tests, and the uncertainty of the exact temperatures to be used. On the other hand the hot plate cannot be said to be a universal apparatus filling all requirements. Window glass, for instance, as ordinarily used cannot be tested on the hot plate. Complete wall sections give more practical results on the hot box than on the hot plate. Each type of apparatus has its place in a research laboratory and therefore both the hot box and the hot plate have been constructed and are now in use at the University of Minnesota.

The principle upon which the hot box is constructed has been previously described but recently changes have been made and the box has been built into one of the walls of a cold storage room making it possible to get temperature as low as 20 deg. fahr. on the cold side of the material and up to 150 deg. on the hot side. A short description of the apparatus will therefore be given. The box is a double or guarded type. One box placed within the other and each with one face open; the open faces being placed in the same plane and covered with the material to be tested.

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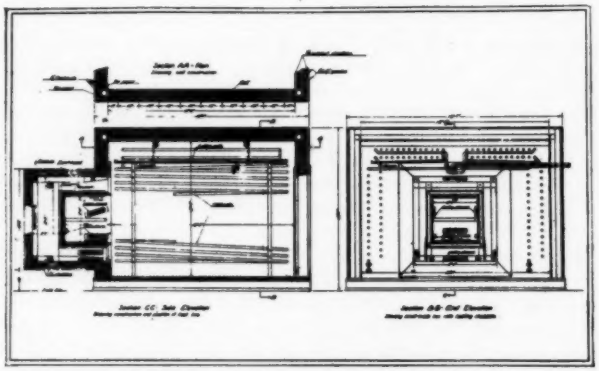
[1] Professor of Mechanical Engineering and Director of the Experimental Laboratory, University of Minnesota.

Paper presented at Semi-Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Lexington, Ky., May, 1926.

The apparatus as constructed is shown in the line drawings—Figs. 1 and 2 and by the photographs of Figs. 3 and 4. Fig. 1 represents a vertical section through the double hot box and cold room; Fig. 2, an end view with the front wall of the cold room removed and looking into the open end of the hot box. It will be noted that the hot box is built into one of the walls of the cold storage room. The dimensions of the large or guard box are 5 ft. cube and the small or inner box, 3 ft. cube. The cold room is 12 ft. square and 8 ft. 4 in. from floor to ceiling. The cold temperature is maintained by a $7^1/_2$ ton ammonia Compression Refrigerating Machine and approximately 1500 linear ft. of $1^1/_4$ in. pipe, 463 ft. of this being placed on each side of the cold room and the remainder in two ceiling coils. The temperatures of the test boxes are maintained by low temperature heating coils distributed throughout the 2 boxes. The locations of these coils were determined by experiment in order to get as nearly uniform temperatures throughout



FIGS. 1 AND 2. DIAGRAMS OF HOT BOX APPARATUS FOR MEASURING HEAT TRANSMISSION

the 2 boxes as possible. The temperatures are controlled by thermostats placed in the boxes but not shown in the drawings. They are further controlled by rheostats placed in series with the heating elements and operated from the outside control panel. All temperatures in the hot boxes are measured with copper constantan thermocouples and a Leeds & Northrup potentiometer, but those of the cold room are measured with Leeds & Northrup resistance thermometers.

Fig. 3 is a photographic view taken from the inside of the cold room and looking into the end of the hot boxes, the test section removed. This view shows the position of the thermostats, the location of the heating elements, and an 8 in. fan which is used to keep uniform temperatures in the inner box. A similar fan is also used in the outer box. The fan speeds are controlled by rheostats and are reduced as low as possible and still maintain uniform temperatures. The small dishes shown in the inner box contain calcium chloride for drying out the air. It was found when testing thin materials, such as single glass, that condensation collected on the inside surface in a sufficient amount to affect the results. In order to get the number of B.t.u.'s passing through the test area, the total energy supplied to the inner box, including the current to the fan, is measured by a watt meter. Fig. 4 is the photographic view of the control panel and instruments. All of the thermocouple wires and heating element controls are carried to this panel.

In order to reduce the number of readings necessary in making a test, the thermocouple switches are so arranged that the temperatures may be read individually or in groups. The individual temperatures are taken while the adjustments are being made and the group or multiple temperatures are taken for those thermometers whose temperatures must be averaged for the tests. Thus there are five temperatures taken in the inner box, over the surface of the test section, six temperatures over the other five sides of the inner box, etc.

Perhaps one of the greatest difficulties met with in the use of this apparatus has been that of getting uniform temperatures over the full area of the test specimen

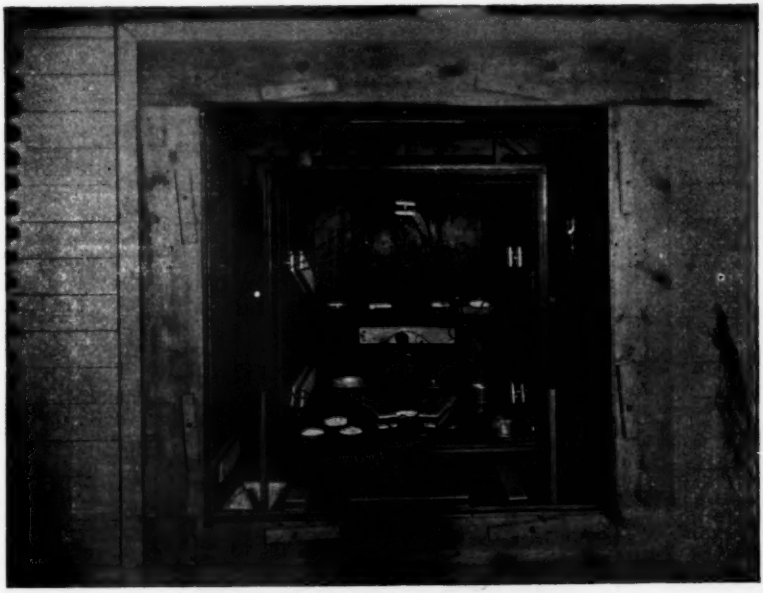


FIG. 3. VIEW TAKEN FROM INSIDE OF COLD ROOM LOOKING INTO HOT BOXES

and in both the outer and inner boxes. If the air remains undisturbed except by the natural convection currents, it will become much hotter at the top part than at the lower part and give erroneous results. On the other hand if the air is circulated too violently, it will reduce the surface resistance and increase the conductivity. The problem therefore has been to give the air just sufficient motion to keep uniform temperatures at the various levels; a problem which requires very careful adjustment. While the temperatures have been automatically regulated with thermostats, it has been found desirable to make final temperature adjustments during the run with rheostats operated from the switchboard outside of the box.

The hot plate used in the laboratory is shown in the line drawings, Figs. 5 and 6, and in the photographic view of Fig. 7. Fig. 7 shows also the rheostats, thermocouples, potentions, and watt meter. The central or heating plate is of standard design, heated by electric heating elements and protected by a guard ring. The

plate is 25 in. square with an 18 in. central or test section. The central 18 in. section is divided from the outer portion by a 1/8 in. insulating slot or groove cut through the face of the plate. The heating elements are made up of 1/4 in. asbestos boards wound with No. 22 gage chromel—resistance wire spaced 1/4 in. and having a resistance of 0.97 ohm per foot.

The temperatures are measured by copper constantan thermocouples extended to a switch block where they may be readily connected to the potentiometer. In making the test two 25 in. square test pieces are used, one placed on each side of the hot plate and the cold plates clamped against the material. The apparatus is brought up to temperature with alternating current from the city lines. After

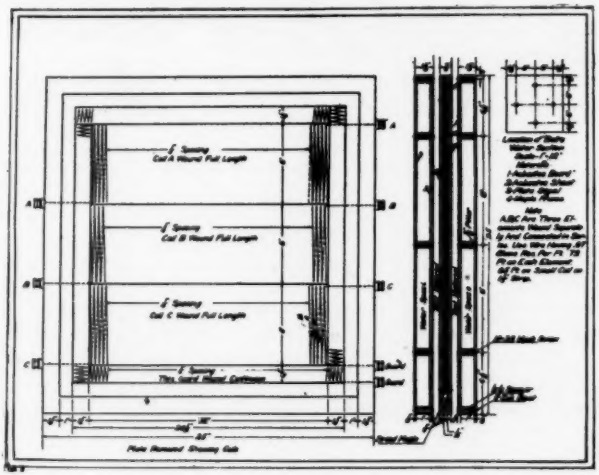
FIG. 4. CONTROL PANEL AND INSTRUMENTS

the temperature has become uniform the alternating current is shut off and direct current from storage batteries is used for making the tests. The direct current gives more uniform results than can be obtained with the alternating current due to variation in the line voltage.

The thickness of the material under test is determined by measuring, with micrometers, the distance between the hot and the cold plates. At present no means have been provided for measuring the pressure exerted by the plates on the material. It is doubtful whether this would be of any great value, as there is no standard pressure to be used and the same pressure on different materials would have entirely different effects. The pressure need only be sufficient to get a good surface contact and should not be so great as to materially reduce the thickness of the test specimen. This must be left largely to the experience of the operator.

The large size of the plate has some advantages over the small plates generally used. Thicker samples may be tested with accuracy and since areas are larger, the unevenness of the materials will be more nearly compensated for. On the other hand it is more difficult to get good surface contact with the larger plate, especially with hard surface material.

A very simple hot plate which has been found effective for comparative tests is shown in Figs. 8 and 9. This plate is heated by steam maintained at a constant pressure. The materials to be compared are placed, one on each side of the plate and the temperature gradient through the materials taken with thermocouples. If the materials are of the same thickness, the temperature drops will indicate which of the two materials is the better. This method cannot be used to give absolute



FIGS. 5 AND 6. HOT PLATE USED TO MEASURE HEAT TRANSMISSION

constants, but a modification of it may however, be used as follows, which will give approximate constants.

Two materials are placed on the same side of the plate, the conductivity of one of them have been previously tested by the standard hot plate method. From the temperature drops through the two materials, the heat transmission constant for the second material may be calculated as follows:

C_1 = the conductivity of the standardized material
C_2 = the conductivity of the material to be tested
t_1 and t_2 = the two surface temperatures of the standardized material
t_3 and t_4 = the two surface temperatures of the materials to be tested
H = the heat in B.t.u.'s passing through each material

Then $H = C_1 (t_1 - t_2)$

also $H = C_2 (t_3 - t_4)$

and $C_2 = C_1 \dfrac{t_1 - t_2}{t_3 - t_4}$

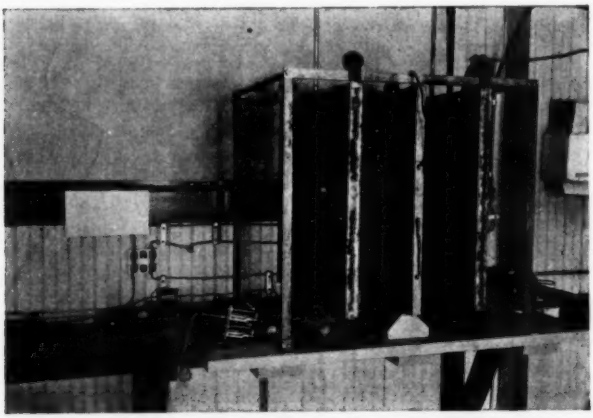


FIG. 7. HOT PLATES SHOWING RHEOSTATS, THERMOCOUPLES, POTENTIONS, AND WATT METER

The temperatures may be determined with thermocouples and, by substitution, the conductivity of the material may be calculated.

Errors in this method arise from the fact that a certain amount of heat will be lost through the edges of the first material and not pass through the second material and also from the fact that the mean temperatures for the two materials are not the same. The plate used in the laboratory is only 8 in. square but reasonably good results have been obtained by making duplicate tests with the position of the material interchanged and averaging the results.

The minimum areas for the different thickness and qualities of material which may be used without unreasonable error has not been determined, but it is evident that as the plate area increases the more nearly accurate the results will be. The

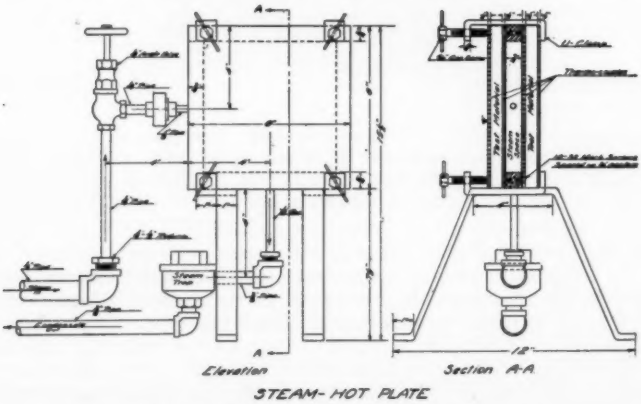


FIG. 8. DIAGRAM OF STEAM HOT PLATE

method is so simple and the readings so easily taken that it seems to have much to commend it for large size wall sections.

For instance, the plate might be built of large area and if low temperatures were desired it might be heated and regulated with electric heating elements. The surface of the plate could be covered with some standard well calibrated and reasonably flexible material, such that the wall section under test could be brought into close contact with it. The heat transmitted through the wall section, with the exception of the end losses, would be the same as that transmitted through the standardized material, and knowing the temperature drops through the material, it could be easily calculated. The required temperatures, as in previous cases, would be measured with thermocouples. This method would eliminate one of the surface resistances of the wall which in thick walls might be negligible; or it could be determined experimentally and the necessary corrections made. The advantage of this method would be simplicity of apparatus and ease of operation. The end losses

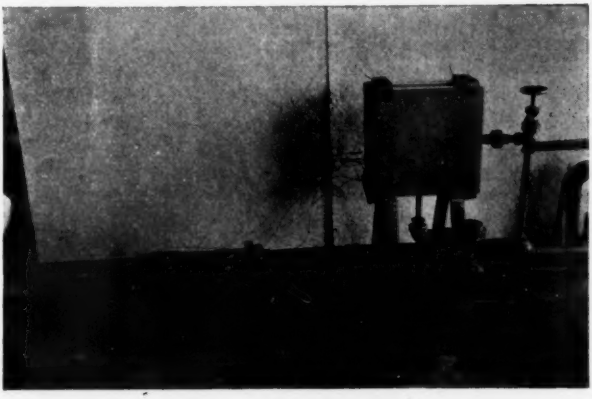


FIG. 9. PHOTOGRAPHIC VIEW OF STEAM HOT PLATE

could be partially eliminated by insulation or if the plate was electrically heated it might be eliminated by a guard ring as in the case of the hot plate. This method is similar to one proposed by Prof. A. J. Wood.

There are arguments in favor of both the hot plate and the hot box methods of testing and in many instances both constants are desirable. An insulating material may be so used that the conductivity only should be considered in determining its effectiveness. On the other hand it may be so applied that the surface resistance is effective, in which case the hot box constants should be used. The real problem is to get a simple and effective method of obtaining both of the constants. Since the hot plate is a much more simple piece of apparatus to operate than the hot box, it would be an advantage if both constants could be determined from the plate with reasonable accuracy. As the only difference between the two constants is the surface resistances, it is only necessary to determine these resistances in order to calculate the hot box constants from the hot plate constants. In an effort to accomplish this in a practical way a special board or support has been built up for use in connection with the hot plate as shown in the photograph of Fig. 10. This support consists of a board in which small pins about $^3/_{16}$ in. in

diameter and 8 in. long are placed. These pins are placed $4^1/_2$ in. on centers and when the support is placed between the material and the cold plate it holds the material in close contact with the hot plate without any appreciable resistance to the circulation of the air over the outside surface of the material. With this arrangement the outside surface temperatures are determined by means of thermocouples placed on the surface and the air temperatures are taken with thermocouples spaced at the proper distance from the surface.

By using the two surface temperatures, the hot plate constant may be determined, or, by taking the outside surface temperature and the air temperature, one of the

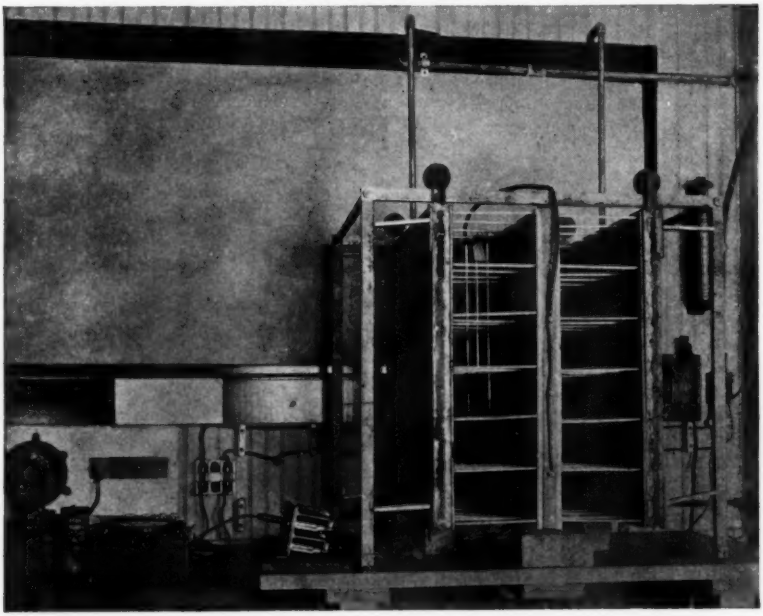


FIG. 10. SUPPORT FOR HOT PLATE

surface constants may be determined. If the two surface constants are assumed to be the same, then the equivalent hot box constant may be calculated by the well known formula

$$K = \frac{1}{1/k_1 + 1/k_2 + x/c}$$

in which K = the hot box constant
$k_1 + k_2$ = the surface resistance
x = the thickness of the material
C = the conductivity.

Tests which have been made on certain insulating materials show very close agreement between the constants as obtained in this manner and those obtained by the hot box. There is probably some error introduced in assuming that the two

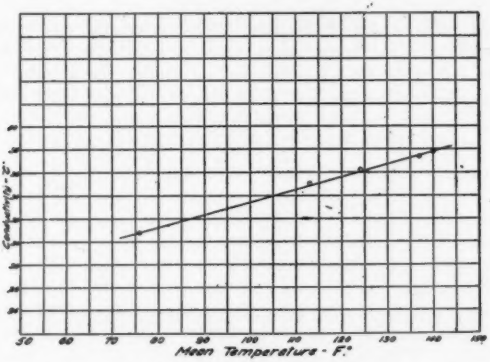


FIG. 11. TESTS RUN ON INSULITE TO DETERMINE RELATION BETWEEN TWO CONSTANTS

surface constants are the same and in making comparisons between the two methods there is the difficulty of getting tests at the same mean temperatures. While the method does not give strictly the hot box constant, it seems that the calculated constant should be sufficiently close for many practical cases where the hot box constant is required.

Table 1 and curve of Fig. 11 show the results of a series of tests run on Insulite in order to determine the relation between the two constants. The hot plate was used and the hot box constants were calculated by the method previously explained. These constants agree very closely with those obtained on the same kind of material using the hot box. Although samples of the same material have not as yet been tested on the hot box, samples of previous materials run 0.39, 0.396, and 0.393. The hot plate constants only have been plotted on the curve sheet and it will be noted that while there is a variation in these constants, they all lie on a straight line and increase as the mean temperature increases. This increase in conductivity with an increase of mean temperature is a characteristic of materials which should be taken into consideration in reporting results of tests and the mean temperatures

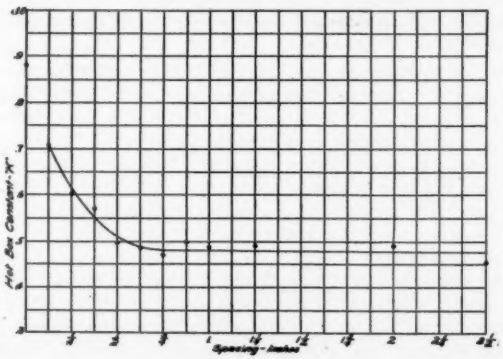


FIG. 12. HEAT LOSSES THROUGH DOUBLE GLASS

should be given. The slope of the line depends upon the nature of the material. Due to the variation, it is essential that report of constants should be accompanied with the mean temperatures at which test is made. In general those materials which have the greatest proportion of air spaces will give the greatest increase in conductivity for a given increase in mean temperature. Sufficient tests have not been made to determine the effect of mean temperatures on surface constants.

One of the ever present problems in insulating is to determine the value of an air space. Air, when not in motion, is a very good non-conductor and in this state the theoretical value of an air space as an insulator should be in direct proportion to its thickness. Unfortunately, however, the air does not remain quiet, but as soon as heat is applied, convection or eddy currents are set up. These convection currents increase as the width of the air space is increased until a point is reached where the effect of the convection currents equals or over-balances the resistance of the air to conduction, and the greater part of the heat is transmitted across the air space by convection. The maximum effective width of an air space is undoubtedly different for different materials, and will depend upon the condition of the surface and its temperature. The position of the air space will also affect its value. A horizontal space with the heat applied to the under side would not be as good an insulator as would the same space with the heat applied to the top. A thorough study of this factor and its effect on insulated wall construction would be extremely valuable.

A series of experiments which have been made at Minnesota to determine the best spacing for double glass for windows may be of interest in this connection. In making these experiments the hot box was used, and tests were made on both one thickness and two thicknesses of double strength glass. When the two thicknesses were used, the space between the surface was varied from $^1/_8$ in. to $2^1/_2$ in., and the tests made under still air conditions. The test areas in which the air had free circulation were three feet square and the air temperatures were taken one inch from the outside surfaces. The average temperature on the high side of the glass was 80 deg. fahr. and on the low side −8 deg. fahr. The results of these tests are shown in Table 2 and the curve of Fig. 12. While there is some variation in the points on the curve, it appears that the best condition is reached at about three-quarters of an inch spacing. From this point up to $2^1/_2$ in. there seems to be but very little difference. This curve would indicate a constant for a double glass of slightly less than 0.5. If, however, the effect of air motion over the surface is taken into consideration, the same as for single glass, the constants will be 0.55, a reasonable constant to use in practice.

A large amount of work has been done by different experimenters to determine the insulating value of various types of building construction. Many of these researches have produced valuable data. Yet when the builder really wants to build a wall which will meet definite requirements with the least reasonable expense, he does not know what to do. There are so many variables entering into the problem and various data are so confusing that the man without special experience cannot find his way out. The greatest needs are first to standardize as far as possible the methods of obtaining and reporting results; and then to get more workable data. If it is possible to develop a simple and direct method of obtaining constants, one which with reasonable care will be sufficiently accurate for commercial purposes, it should be seriously considered. The hot plate as ordinarily constructed seems to fill these requirements, but there are cases in wall construction where the hot plate constant is not sufficient, and the ordinary method of obtaining the hot box constant is either too expensive or too inaccurate. The subject of heat transmission

is one which deserves very careful study and research by the heating and ventilating engineer.

TABLE 1

Insulite 0.435 In. Thick
Weight 18.9 Lbs. per Cubic Foot

Test No.	Mean Temp. Deg. Fahr. Surface to Surface	Hot Plate Constant C	Surface Constant k	Hot Box Constant K
1	76.2	0.3082	....	....
2	113	0.350	....	....
3	124.2	0.362	1.47	0.391
4	125	0.362	1.52	0.398
5	137	0.374	1.435	0.391
6	140	0.378	1.56	0.411

NOTE: Tests Nos. 1 and 2 were made with both the hot and cold plates in contact with the material. Therefore, no hot box constant could be determined. The hot plate constant is calculated in terms of one inch thickness of material. The hot box constant is calculated in terms of material as tested.

TABLE 2—HEAT LOSSES THROUGH DOUBLE GLASS

No. of Thicknesses of Glass	Spacing Inches	Air Temperatures Deg. Fahr., 1 In. from Glass Surface		Mean Temperature	Transmission Constant K
		High Side	Low Side		
1	0	80.1	+ 4.0	42.1	0.887
2	1/8	77.5	−10.3	43.9	0.708
2	1/4	80.6	−11.5	46.0	0.594
2	3/8	80.1	−15.2	47.6	0.573
2	1/2	80.3	−14.3	47.3	0.495
2	5/8	78.9	−13.7	46.3	0.487
2	3/4	79.5	−14.3	46.9	0.471
2	1	80.5	− 1.3	40.9	0.488
2	1 1/4	79.8	−10.8	45.3	0.494
2	2	81.5	+ 0.2	40.8	0.494
2	2 1/2	80.5	+ 0.2	40.4	0.457

DISCUSSION

PROF. J. D. HOFFMAN: I would like to ask Professor Rowley if in any of his tests or experiments he had the glass in the horizontal position instead of a vertical position, or were all tests conducted with the glass in the vertical position? Also if they were all conducted in a vertical position, whether or not there was a temperature gradient from the bottom to the top of the glass, and if so, was that temperature gradient relieved by the movement of the air?

PROF. L. M. ARKLEY: I would like to ask Professor Rowley how long it takes to establish the heat gradient or the heat transfer through the wall. That, of course, will vary with the different kinds of material he is testing. What is the exact area he uses? That is, is it correct to use the area in the box method which is actually shown on his sketch?

C. A. BULKELEY: Since double glass spaced three-quarters of an inch has been found to be as good as any spacing, it lends itself to a single sash with double glass. I would like to know if there has been discovered either by the Professor or anyone else, any way to install double glass in a single sash and make it airtight enough so that the inner surfaces of the glass will not become dirty.

C. GOTTWALD: I would like to inquire the temperature (maximum temperature) of the different methods of testing the box, plate, and steam apparatus.

PROFESSOR F. B. ROWLEY: Referring to the first question of Mr. Hoffman: The glasses were all tested in a vertical position. If they had been tested in a horizontal position, we would expect different results. A horizontal air space would be a good insulator, if the heat were going down, but if the heat was applied at the bottom of the air space, convection currents would be set up which would greatly reduce the efficiency as an insulator.

The second question was in regard to the temperature gradient from the top to the bottom over the test area. We have found in this work that it is impossible to keep uniform temperatures over the vertical walls unless some sort of artificial circulation is resorted to. We have found that a slow moving fan, giving just sufficient velocity to relieve the temperature difference gives the best results.

The third question, I believe, was in regard to the time required to establish a uniform heat gradient through the wall. This varies with the different walls constructed. We have had some walls under test where the time required was two to three days to get uniform heat flow. In one set of walls in particular, the transmission constant continued to decrease for four days after which it became normal. This may have been due partially to the fact that the walls were not thoroughly dried out. It has been our practice to keep the temperature constant at least a day before the tests are started.

The fourth question covers the spacing of the glass for the tests. As far as our tests have gone, we have found that the three-quarter inch spacing gives as good results as anything wider. For spaces less than three-quarters of an inch, the insulating value is not as high. The area of the test section, that is, three feet square, was separated by strips so that the air circulation currents were confined to this area.

The fifth question covers the temperature range of the different test apparatus. In the hot box the temperatures range from 75 deg. fahr. on the hot side of the wall to a −20 deg. or less on the cold side, and in some cases 30 deg. fahr. below zero has been used. The temperatures of the electric hot plate run from 100 deg. fahr. to 250 deg. fahr. on the hot side, depending upon the current used down to about 40 on the cold side, depending upon the temperature of the circulating water. In the steam plate, the steam pressure is regulated at about two pounds gage, giving temperatures of approximately 220 deg. fahr.

No. 749

DEVELOPMENT AND CHARACTERISTICS OF A CARBON MONOXIDE RECORDER[1]

By S. H. KATZ,[2] D. A. REYNOLDS,[3] H. W. FREVERT[4] AND J. J. BLOOMFIELD[5]

PITTSBURGH, PA.

INTRODUCTION

VEHICULAR tunnels have created new problems in ventilation engineering, and as ventilation of mines is a phase of investigations of the Bureau of Mines, in 1920 the Bureau was asked by the New York State Bridge and Tunnel Commission to assist in obtaining data for a ventilating system for the Hudson River vehicular tunnels (now the Holland tunnels), now almost completed between New York City and Jersey City. The data obtained for the Holland tunnels is applicable at the Liberty tunnels recently completed at Pittsburgh, Pa. To protect the health and safety of the public passing through long vehicular tunnels necessitates maintaining continuous ventilation to dilute the exhaust gases to a harmless degree and remove them from the tunnels.[6] Four parts of CO in 10,000 of air was determined as the maximum concentration to which a person may be continuously exposed without noticeable effects; or, if the concentration is increased from zero uniformly for one hour, the maximum tolerable concentration is six parts per 10,000, averaging 3 parts for the hour.[7] Accordingly, the ventilating machinery for the Holland and Liberty tunnels was designed to maintain the CO below these concentrations under all traffic conditions.

The adequacy of the ventilation of the tunnels when in use can be determined by a staff of chemists analyzing samples of the tunnel atmosphere, or else by automatic apparatus to analyze and record continuously the concentrations of carbon monoxide. Recording apparatus were deemed preferable as well as much less expensive to maintain. However, as heretofore no automatic apparatus had been made capable of recording continuously the very low percentages of CO, development of a suitable CO recorder was undertaken by the Bureau of Mines. The principle employed is measurement by means of thermocouples of the increased

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[1] Published by permission of the Director, Bureau of Mines, Department of Commerce.

[2] Associate Physical Chemist, Pittsburgh Experiment Station, Bureau of Mines. Submitted by the senior author to the faculty of the University of Pittsburgh as partial requirement for degree of Doctor of Philosophy.

[3] Assistant Chemist, Pittsburgh Experiment Station, Bureau of Mines.

[4] Junior Physical Chemist, Pittsburgh Experiment Station, Bureau of Mines.

[5] Junior Chemist, Pittsburgh Experiment Station, Bureau of Mines.

[6] Fieldner, A. C., Henderson, Yandell, Paul, J. W., Sayers, R. R., and others, Ventilation of Vehicular Tunnels, JOUR. A.S.H.&V.E., vol. 32, 1926, pp. 17 to 36, 79 to 100, 153 to 158, et seq.

[7] Henderson, Yandell, Haggard, H. W., Teague, M. W., Prince, O. L., and Wunderlich, R. M., Physiological Effects of Automobile Exhaust Gas and Standards of Ventilation for Brief Exposures, *Jour. Ind. Hyg.*, vol. 3, Aug., 1921, pp. 72–92, and 137–146.

Paper presented at Semi-Annual Meeting of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Lexington, Ky., May, 1926.

temperature of the gases when the CO and oxygen react chemically in presence of a catalyst, the thermoelectric effects being recorded by means of a recording potentiometer. After extended experimentation and development, a recorder was produced which is not appreciably affected by the presence of other gases, and which is capable of indicating and continuously recording the highly diluted CO.

Acknowledgments

This investigation was undertaken at the suggestion of A. C. Fieldner, chief chemist and superintendent of the Pittsburgh Experiment Station of the Bureau of Mines. Arrangements for installation of the recorder at the Liberty tunnels were made by A. D. Neeld, consulting engineer for the Commissioners of Allegheny County, Pa., for the Liberty tunnels. H. C. Bashioum, professor of industrial chemistry in University of Pittsburgh, was advisor throughout the study. F. L. Bishop, Dean of the Engineering School of the University, was consulted freely. The following employees at the Pittsburgh Experiment Station assisted: L. F. Perry, J. A. Rowe, P. A. Collins, F. C. Donath and W. P. Yant.

Previous Development of Principles and Instruments

The principle of indicating the presence of combustible gases in air by a differential temperature effect induced by the gases when in contact with a catalyst to promote oxidation, dates back many years. In 1889, Pitkin and Niblett[8] devised an instrument consisting of two thermometers in a case pervious to gases; one thermometer was coated about the bulb with platinum black, the other was plain. The thermometers showed the same temperature indications when in pure air, but when combustible gases such as hydrogen or gases in a mine were present, the platinized thermometer indicated a higher temperature than the other, and the concentration of such gases could be estimated from the temperature rise.

Williams and Williams[9] in 1915 patented an instrument using a case pervious to gases, a catalyst, differential thermocouples, and a galvanometer; they combined a signaling device with it. The two opposing junctions of the thermocouple were covered with porous "buttons," one of which was plain and the other impregnated with finely divided platinum or palladium. The buttons were equally heated by means of similar platinum resistances wound about them, and were electrically connected in series together with a battery. The thermoelectric circuit included a galvanometer or millivoltmeter and a relay. In impure air the galvanometer indicated the percentage of the deleterious gas. When sufficient gas was present, the relay closed a second circuit of greater power, which rang a warning bell.

Chance and Chance[10] obtained a patent in 1919, according to which a mercury-filled bulb joined to an upright tube was surrounded by a catalyst, which in turn was surrounded and heated by a liquid bath maintained at boiling; air was drawn through the catalyst by means of an exhauster or by a chimney effect. The copper-oxide catalyst acted on carbon monoxide and hydrogen, but did not oxidize methane unless kept at some higher temperatures. The mercury stood at a predetermined height so long as air only was present. When sufficient CO (or other combustible gas) entered, the mercury rose because of the greater heating and closed an electric circuit, causing a signal to operate.

[8] Pitkin, J., and Niblett, J. T., Improvements in Instruments for Indicating the Presence of Hydrogen Gases or Firedamp in Mines or Other Places, British patent 4629, 1889.
[9] Williams, A., and Williams, L. D., Contrivance for Automatically Detecting the Presence of Certain Gases and Vapors, U. S. patent 1143473, June 15, 1915.
[10] Chance, T. M., and Chance, E. M., Detecting Combustible Gases, U. S. patent 1298890, April 1, 1919.

In 1917 the Bureau of Mines undertook investigations of war gases. These led through numerous ramifications,[11] including the development of hopcalite, a catalyst which causes oxidation of CO in air at ordinary temperatures.[12] The hopcalite is a specially prepared mixture of manganese dioxide and copper oxide in granular form,[13] and was first used in gas-mask canisters for the purpose of destroying CO.[14] Although it was known about 40 yrs. before that some base metal oxides cause, at low temperatures, catalytic oxidation of CO in the presence of oxygen,[15] the knowledge was not applied practically until hopcalite was made and used in the gas masks.

While testing the action of CO gas-mask canisters, Lamb and Larsen[16] used a CO tester consisting of a platinum catalyst surrounding one junction of a pair of differential thermocouples, which were held in a tube through which a steady stream of the gas passed. The series of tubes was enclosed in a vapor bath of diphenylamine to hold an elevated, uniform temperature of 325 deg. cent. The thermocouple leads connected with a galvanometer which indicated a difference in potential between the thermocouple junctions when CO is present. Deflections of the galvanometer were calibrated against known concentrations of CO in air passed at a uniform rate. Lamb and Larsen[17] also described hopcalite in a gas detector applied to gas-mask canisters to signal the presence of CO by closing an electric circuit through expansion of bimetallic strips caused by the heat of oxidation of CO, or by the effect of the heat on one junction of a thermocouple, in circuit with a potential indicator; they mention that soda lime and charcoal gas purifiers may precede the hopcalite. Another device for warning of the presence of CO, made with bimetallic strips in presence of a catalyst, was recently tested in South Africa.[18]

Some instruments had been made previously to record relatively high concentrations of CO,[19] but they are quite different in principle to those heretofore described, and so need no further attention here.

Certain devices which were employed for other purposes have been incorporated in the mechanism of the CO recorder to be described. These will include the flow-

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[11] Manning, Van H., War Gas Investigations, *Bull.* 178-A, Bureau of Mines, 1919; Chapter from *Bull.* 178, War Work of the Bureau of Mines.

[12] July 1, 1918, the Bureau of Mines war gas investigations were transferred to the Chemical Warfare Service, U. S. Army, which had then been recently organized. Since Jan. 1, 1919, the Bureau has investigated and developed gas masks for industrial purposes at its Pittsburgh Experiment Station.

[13] Frazer, J. C. W., and Scalione, C. C., Catalyst and Process for Making It, U. S. pat. 1345323, June 29, 1920.

[14] Lamb, A. B., Bray, W. C., and Frazer, J. C. W., The Removal of Carbon Monoxide from Air, *Ind. Eng. Chem.*, vol. 12, March, 1920, pp. 213–221.

Katz, S. H., Bloomfield, J. J., and Fieldner, A. C., The Universal and the Fireman's Gas Mask, *Tech. Paper* 300, Bureau of Mines, 1923, 22 pp.

[15] Wright, C. R. A., and Luff, A. P., Researches on Some Points in Chemical Dynamics, *Jour. Chem. Soc.*, vol. 33, 1878, pp. 1–27 and 503–545.

[16] Lamb, A. B., and Larsen, A. T., The Rapid Determination of Carbon Monoxide in Air, *Jour. Amer. Chem. Soc.*, vol. 41, Dec., 1919, pp. 1908–1921. Also, Testing Gases: U. S. pat. 1321063, Nov. 4, 1919.

[17] Lamb, A. B., and Larsen, A. T., Gas Detector, U. S. pat. 1416361, May 16, 1922.

[18] Vaughn, J. A., Notes on a Carbon Monoxide Detector and Alarm: *Jour. South African Inst. Engrs.*, vol. 22, Feb., 1924, pp. 98–103.

[19] Anon., A New Automatic Oxygen, Carbon Monoxide and Carbon Dioxide Recorder: *Met. Chem. Eng.*, vol. 16, 1916, pp. 542–544.

Rideal, E. K., and Taylor, H. S., Apparatus for Indicating and Recording Quantities of Carbon Monoxide in Hydrogen or Other Gases: Canadian pat. 204994, Oct. 26, 1920.

Taylor, G. B., and Taylor, H. S., Automatic Volumetric Analysis Carbon Monoxide Recorder: *Ind. Eng. Chem.*, vol. 14, Nov., 1922, pp. 1008–1010.

Anon., Novel Recorder Will Indicate CO Content: *Eng. Min. Jour. Press*, vol. 116, Dec. 8, 1923, p. 1011.

Palmer, P. E., and Weaver, E. R., Thermal Conductivity Method for the Analysis of Gases: Bureau of Standards, Technologic Paper No. 249, Jan. 7, 1924, 100 pp.

Anon., At Last: A CO Meter: *Fuels and Furnaces*, vol. 1, Oct., 1923, pp. 471–2.

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meter of Fieldner, designed for use in testing canisters with gases,[20] and the device of Mase[21] for maintaining a constant flow of gases.

Since January 1, 1919, the Bureau of Mines has continued at its Pittsburgh Experiment Station to develop CO gas masks for use in mines and other industries. Although development of the CO recorder proceeded partly in conjunction with gas-

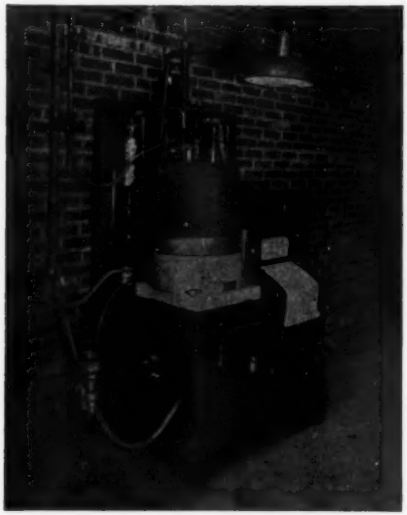

FIG. 1. CARBON MONOXIDE RECORDER AT LIBERTY TUNNELS

mask studies, the active undertaking was initiated by the need of continuously recording the CO in vehicular tunnels.

Principle of Carbon Monoxide Recorder

When carbon monoxide (CO) unites chemically with oxygen (O_2) to form carbon dioxide (CO_2), according to the equation

$$2CO + O_2 = 2CO_2 + \text{heat}$$

the heat liberated increases the temperature of the gases themselves and the matter in contact with them. The recorder uses this effect as a means of indicating as well as recording the concentration of the CO in air. Hopcalite catalyst is employed to promote the union of the CO and O_2. Thermocouples generate electric potentials which increase with the temperature, hence with the CO, and the effects are recorded by a recording potentiometer. The recording potentiometer includes mechanism to operate electric bells or signals when the CO attains a concentration of 4 parts per 10,000, or it may be set to ring at other predetermined concentrations.

[20] Fieldner, A. C., Methods and Apparatus for Testing Canisters, U. S. pat. 1307813, June 24, 1919.

[21] Mase, R. P., Constant Flow Gas Regulator, U. S. pat. 1494856, May 20, 1924.
Oberfell, G. G., and Mase, R. P., An Automatic Compensating Flowmeter, *Ind. Eng. Chem.*, vol. 11, Apr., 1919, pp. 294–296.

Fig. 1 shows the CO recorder installed at the fan house of the Liberty tunnels. The parts are all mounted upon a stand composed of a table 24 by 40 by 30 in. high, with a backboard, 40 by 48 in. attached. The top of the backboard stands $5^1/_2$ ft. above the floor. The table has a shelf 24 by 40 in., 6 in. above the floor; a drawer is included under the table top.

Fig. 2 is a diagram of the essential parts of the apparatus. Arrows indicate the course of the gas from left to right. The gas is drawn through pipes leading from the air ducts of the exhaust fans to a motor-driven blower *a* which forces it through the remaining apparatus. Gas drawn by the pump in excess of requirements is wasted through a side outlet with a hand-regulated globe valve, as shown.

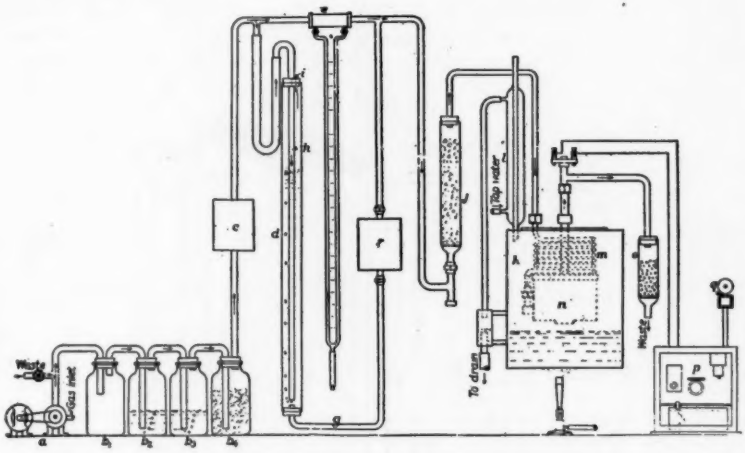

FIG. 2. DIAGRAM OF ESSENTIAL PARTS OF CARBON MONOXIDE RECORDER

The gases pass on through the four bottles (b_1, b_2, b_3, b_4) in series, the second and third of which contain sulphuric acid wash to dry the gases and remove hydrocarbons, ammonia and other gases soluble in or retained by sulphuric acid. The first and fourth bottles serve as traps to prevent passage of acid to other parts of the apparatus. The gases next pass through a receptacle *c* containing a mixture of granular activated charcoal and soda-lime or other caustic, and filters of absorbent cotton. These allow the air and CO to pass through but retain all other gaseous impurities or suspensoids which may materially affect the catalyst following. Hydrogen (H_2), methane (CH_4) and some carbon dioxide (CO_2) if present, are not restrained but these gases (at their low concentrations) do not impair the accuracy of the apparatus because methane is not oxidized by nor does it affect the catalyst at the temperatures employed; hydrogen, as will be shown later, has an effect so small that it may be disregarded, and carbon dioxide is inert.

The pieces *d*, *e* and *f*, will be considered together: *d* is a water well used to adjust the rate of gas flow; *e* is an orifice type flowmeter with water-filled manometer to indicate the flow; and *f* is a reservoir of water which drains into *d* through tube *g*. An escapement tube *h*, for gas, dips into the well *d;* this allows gas to pass out

through an opening i when the gas pressure in the apparatus equals the hydrostatic pressure. Varying the depth of the escapement tube in the water adjusts the flow of gas through the flowmeter. The arrangement of d, e and f and connections maintains a constant flow of gas, regardless of variations in the resistance of the succeeding parts of the apparatus. This constant flow is accomplished by increasing, or decreasing, automatically and equivalently, the depth of water in well d as the pressure in the apparatus increases through any increased resistance to the flow of gas. A constant pressure difference is thereby maintained across the

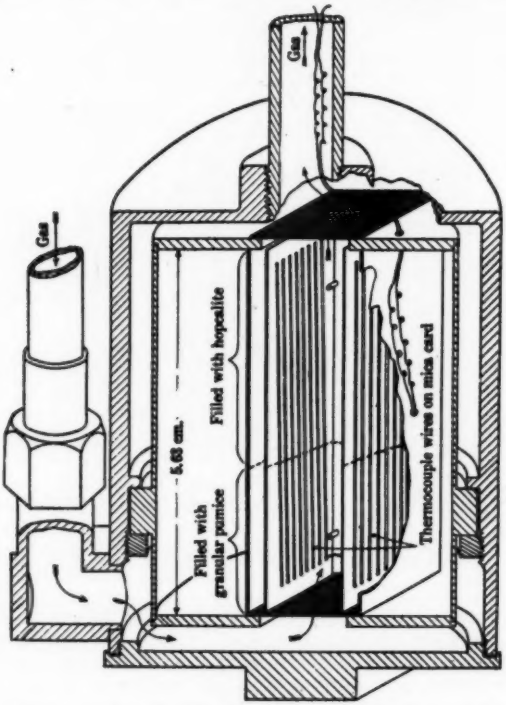

FIG. 3. DETAILS OF CELL CONTAINING THERMOCOUPLES AND CATALYST

orifice of the flowmeter,[22] gas always escaping from the tube h, hence the rate of flow remains constant.

The gases pass to the receptacle j containing broken, fused calcium chloride ($CaCl_2$) to remove any additional water vapor. From there they pass to the steam bath k, heated by a gas flame. A reflux condenser l, stops escape of steam and also constitutes a vent which maintains atmospheric pressure in the steam bath. The bath thus provides a temperature as constant as the barometer. The gas passes

[22] Oberfell, G. G., and Mase, R. P., An Automatic Compensating Flowmeter, *Ind. Eng. Chem.*, vol. 11, Apr., 1919, pp. 294–296.
Mase, R. P., Constant Gas Flow Regulator, U. S. pat. 1494856, May 20, 1924.

through coil m in the steam bath, where it is heated to steam temperature, 100 deg. cent., then through the box n, which contains the thermocouples and the catalyst to cause the reaction.

Details of the box are shown in Fig. 3. Forty-eight differential thermocouples with soldered junctions are arranged in series on two mica sheets held in a cell mounted in the box. Although not shown in Fig. 3 the ends of the thermocouple wires extended beyond the junction and away from the cards to engage the gases and conduct heat to and from the junctions. The leads from the couples extend to binding posts on top of the steam bath. Granular pumice stone surrounds the lower thermo-junctions. The granular catalyst of hopcalite surrounds the upper thermo-junctions, and imparts to them the increased temperature due to the chemical action. Hopcalite from one lot only, was used in the tests recorded hereafter in order to insure uniformity. A trapped air space around the cell serves to insulate it against loss of heat laterally. The gases pass through the cell and

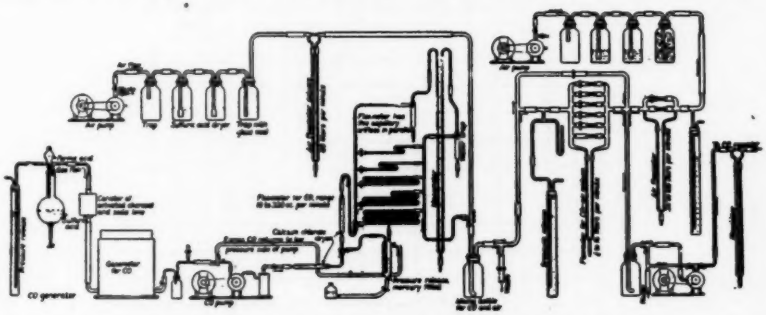

FIG. 4. DILUTING APPARATUS FOR CONTINUOUSLY PRODUCING CARBON MONOXIDE DILUTED WITH AIR TO CONCENTRATIONS BETWEEN 1 AND 5000 PER MILLION

from the box and escape through the receptacle o (Fig. 2) which contains charcoal and calcium chloride.

The electric potentials impressed on the leads from the thermocouples are communicated to a recording potentiometer p, graduated to indicate CO in parts per 10,000, and record it with ink in a continuous line on a time chart.

The mechanism of the recording potentiometer is provided with electric contacts to ring the bell q as a warning should the CO exceed a predetermined concentration. This system can be made to operate a relay switch, thereby automatically increasing the ventilation through electrically driven fans, or it can control other processes in which CO may be a factor or be made a factor.

Laboratory Tests of the Recorder

Many types of recorders constructed during development were tested in the laboratory with synthetic mixtures of CO and air. It became necessary to provide large volumes of air with CO admixed in any desired concentration from 1 to 10,000 parts per million (latter = 100 parts per 10,000, or 1 per cent). This led to construction of the "diluting apparatus," a system of gas pumps for air and for CO, flowmeters,[23] mixing jars and delivery tubes, shown diagrammatically in Fig. 4.

[23] Benton, A. F., Gas Flowmeters for Small Rates of Flow, *Ind. Eng. Chem.*, vol. 11, 1919, pp. 623–629.

The figure is self-explanatory. As the tests of the recorders were based largely on the concentrations obtained with the diluting apparatus, precision of the dilutions was essential. Each flowmeter of the diluting apparatus was carefully calibrated. Purity of the CO used was determined and the recording potentiometers were calibrated.

Accuracy of Diluting Apparatus

Flowmeters of the diluting apparatus were calibrated by comparing the heads of water in the manometers against flow rates determined with a gas meter attached in series and discharging into room air, or by determining the volumes delivered into gas burettes in measured times. A representative calibration of one of the capillary tube flowmeters for CO, by the gas burette method, is shown in Fig. 5.

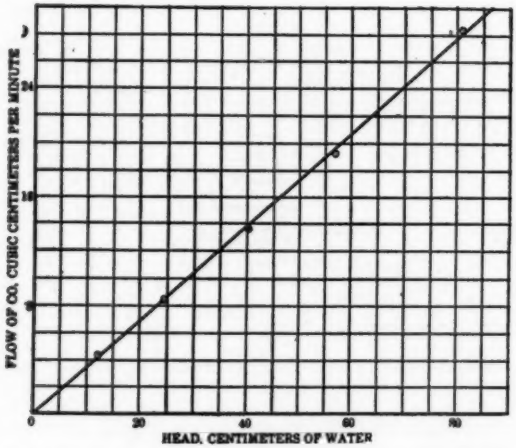

FIG. 5. CALIBRATION OF A FLOWMETER WITH GLASS CAPILLARY ORIFICE, ABOUT 0.5 MM. DIAMETER BY 1.1 METER LENGTH, FOR DELIVERING CARBON MONOXIDE AT LOW RATES OF FLOW

The capillary was about $^1/_2$ millimeter in diameter by 1130 mm. long. The flows through the capillaries are directly proportional to the heads of water or pressure differences, as stated by Poiseuille's law.[24]

Deviations of the determined points from the straight line are due more probably to errors of observation and manipulation than to irregularities in gas flow. The greatest deviation of points from the line in Fig. 5 amounts to 3 per cent, while the average deviation of the five points is less than 2 per cent. The latter figure may be taken as the average error of the measurement of the gases by flowmeter. Flowmeters were used only at water heads exceeding 10 and up to 120 centimeters.

The flowmeters for measuring the large volumes of air do not give straight-line

[24] Poiseuille, J. L. M., Recherches Experimentales sur le Mouvement des Liquides dans les Tubes de Tres Petites Diametres, *Compt. Rend.*, vol. 15, 1842, pp. 1167–1196.
Washburn, E. W., Principles of Physical Chemistry, 2nd ed., 1921, McGraw-Hill Book Co., New York, pp. 61–3.

calibrations because the flow of air becomes turbulent due to the larger orifices. The calibration of a flowmeter designed to deliver 60 liters of air per minute is shown in Fig. 6. The orifice was a glass tube approximately 5 mm. in diameter by 55 mm. long.

Since several flowmeters were used concurrently, in series or parallel, cumulative errors could increase the inaccuracies beyond the 2 per cent average of the individual flowmeters. However, it is improbable that the total errors of dilutions exceeded an average of 5 or 6 per cent. The dilutions were checked by analyzing samples of the mixtures with the Haldane apparatus, the most accurate gasometric

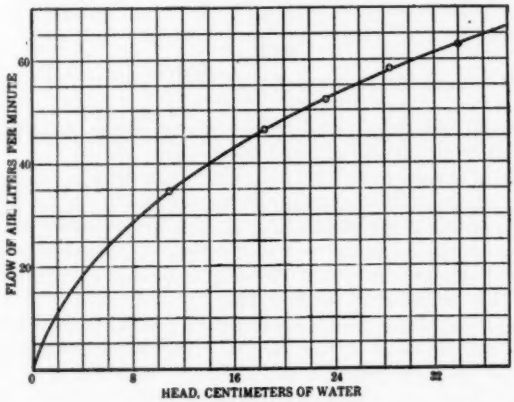

FIG. 6. CALIBRATION OF A FLOWMETER TO DELIVER 60 LITERS OF AIR PER MINUTE, ORIFICE IN GLASS APPROXIMATELY 5 MM. DIAMETER BY 55 MM. LONG

method, and they appeared fully as accurate as the Haldane method which may vary by 2 parts in 10,000.

Purity of the Carbon Monoxide

Carbon monoxide was made by dropping formic acid into heated sulphuric acid. It was then passed through a gas-mask canister of activated charcoal and soda-lime to remove vapors of formic acid and sulphur dioxide, and was then stored in a laboratory gasometer of 5 cu. ft. capacity. A number of samples of gas taken from the gasometers at different times gave analyses of 97.8 to 98.5 per cent by the combustion method with Orsat apparatus. Since the differences only slightly exceed the errors of analysis, the CO was considered 98 per cent pure, and allowance was made accordingly in computing the calibration of recorders.

Calibration of Recording Potentiometers

Four Leeds and Northrup recording potentiometers with scale paper 10 in. wide were used. The instruments had ranges across the paper of 3.16, 10, 17.9 and 30 millivolts, respectively. (The instrument with 3.16-mv. range was made originally with 10-mv. range, but was modified to increase its deflections.) All the instruments were adjusted to indicate zero potential at a point one inch from the left

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TABLE 1. CALIBRATION OF RECORDING POTENTIOMETER OF 10 MILLIVOLTS RANGE
External resistance less than 1 ohm

(Record scale is 10 in. wide, and nominally indicates 1 millivolt per inch)

Impressed potential, millivolts	Deflection of record line from zero, measured inches	Deviation from nominal scale, millivolts
0.902	1.00	+0.10
2.024	2.00	—0.02
3.000	2.96	—0.04
4.015	3.97	—0.05
5.014	4.98	—0.03
5.987	5.92	—0.07
7.024	6.98	—0.04
8.179	8.07	—0.11
	Average	±0.06

edge of the scale, so as to show occurrence of any chance negative potentials as well as the positive potentials due to oxidation of CO.

The deflections of each instrument registered in ink on the scale paper were calibrated against various impressed potentials, accurately determined with a standard potentiometric system in the physics laboratory of the Bureau of Mines. Calibration of the recording potentiometer of 10-mv. range is presented in Table 1. The average error of the inked record is 0.06 inch, equivalent to 0.06 millivolt, or less than 1 per cent of the range of the recording potentiometer.

During the earlier tests of the CO recorders, the potentials, developed by the thermocouples were determined by the recording potentiometers and checked by a Tinsley *vernier potentiometer* and galvanometer, sensitive to 1 microvolt. It was ascertained after usage that the recording instruments were entirely reliable for the purposes, whereupon the Tinsley potentiometer was discontinued.

The recording potentiometers used may be accepted then, as inherently accurate to 1 per cent of their scale ranges; however, this degree of accuracy remains only when the external circuits (containing the thermocouples) include total resistances which are comparatively low. On external circuits having total resistance of 1 ohm or less, the recording potentiometers of 10-, 17.9-, and 30-mv. ranges repeatedly indicated the same line of potential whether approach was from right or left; the instrument with 3.16-mv. range approached its line to ± 0.05 in. When 30 ohms was introduced into the latter's circuit the discrepancy increased to ± 0.4 in., equivalent to 0.125 mv. or ± 4 per cent of the range. External resistance also decreased the speed of response of all the recorders; hence the resistance in circuits of CO recorders should be kept low. If they do not exceed, say 2 or 3 ohms, the indications of the recording potentiometers may be accepted as accurate to 1 per cent, and errors from this source may be considered unimportant.

CHARACTERISTICS OF RECORDERS

Effect of Changing Rate of Gas Flow

The quantity of heat liberated by oxidation of CO in the catalytic cell depends upon the concentration of the CO, the rate at which gas is passed through the cell, and the proportion of the CO which is oxidized. Some of the heat is lost by conduction; that remaining increases the temperature of the gases themselves, and of the catalyst, thermocouples and parts of the apparatus in contact with the gas

during and after the reaction. If the concentration of the CO is uniform, a condition is reached eventually when no further rise in temperature occurs, then all the heat is dissipated through conduction and through removal in the gas stream. With increasing rates of gas flow, up to certain limits, the more rapidly the parts are heated to a temperature of equilibrium, the more rapid becomes the response of the recorder, and its sensitivity becomes greater.

On the other hand, the catalyst is limited in the rate at which it can bring about the reaction, so that considerable CO gas escapes unburned at excessive rates of flow.

The effects of different rates of gas flow on the potentials developed by the thermocouples are shown in Fig. 7. The cell contained 48 differential couples in series, within a cell volume of 100 cc., the depth being 5.63 cm.; the upper and lower

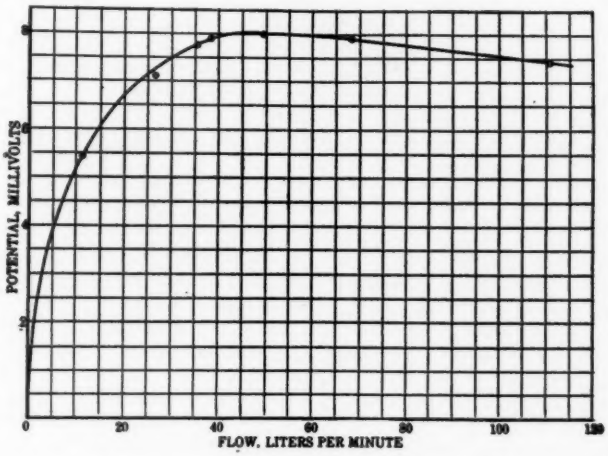

FIG. 7. GRAPH SHOWING EFFECTS OF INCREASING RATES OF GAS FLOW ON POTENTIALS DEVELOPED BY THERMOCOUPLES

thermo-junctions were stationed 4.15 cm. apart and were 0.74 cm. from the top and bottom of cell; the cell was filled with 60 cc. of 8 to 20-mesh hopcalite, above 40 cc. of 8 to 20-mesh granular pumice. Carbon monoxide in uniform concentration of 600 parts per million was used for testing. Maximum potential, as shown by Fig. 7, developed at a flow of 46 liters per minute. The curve is rather flat at this point, so that minor variations of flow produce only a negligible change in potential; advantage is taken of this in practical operation. However, the peak becomes increasingly sharp in curves of greater concentrations of CO, and *vice versa* for lower. At rates of flow below 40 liters per minute, flow changes cause relatively large changes in potential; at rates above 50 liters per minute the changes of potential are less pronounced.

Although the thermoelectric effects are greatest at the best rate of flow, considerable CO escapes unburned. A cell of 24 couples was operated at a flow of 33 liters per minute (best rate) and the outgoing gas was then passed through a second apparatus. A nearly constant proportion of 15 per cent of the incoming CO

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escaped when the gas entering the 24-couple cell ranged up to 40 parts per 10,000. The best rate is thus determined by a balance between the amount of heat produced, the loss of heat by conduction, and the escape of proportionally more unoxidized CO at the higher rates of flow.

The best rate of flow was determined for each cell before it was calibrated. Calibrations against different concentrations of CO in air were then made at the best rate of flow. Calibration of the 24-couple cell is shown in Fig. 8. The calibration is evidently a slightly curved line, greater potential effects than the direct ratio showing at the higher concentrations, due probably to the more effective oxidation of CO at the higher temperatures.

A similar curvature was found by Lamb and Larsen[25] using a platinum catalyst

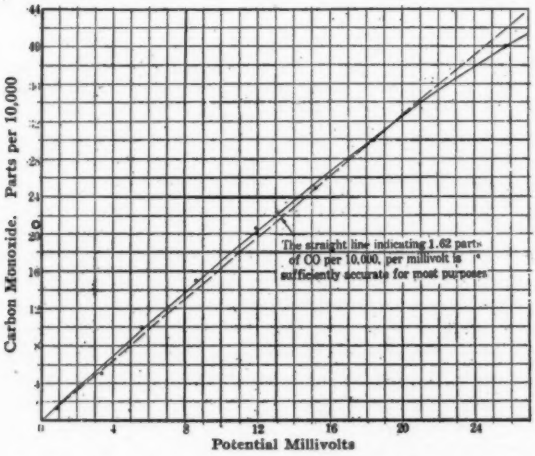

FIG. 8. CALIBRATION OF CELL CONTAINING 24 DIFFERENTIAL THERMOCOUPLES AGAINST CARBON MONOXIDE AT VARIOUS DILUTIONS IN AIR AND BEST RATE OF FLOW (33 LITERS PER MINUTE)

with CO, but they ascribe the curvature to a lesser loss of heat by conduction through oxidation of the CO at higher concentrations within a smaller volume or reaction zone.

For most practical purposes the straight line, indicated by dashes in the graph may be accepted as the calibration; it indicates about 0.62 millivolt developed for each 1 part CO per 10,000, or each millivolt represents 1.62 parts of CO per 10,000 parts of air.

Effect of Depth of Hopcalite

The effect of varying depths of hopcalite was determined in a cell of 12.90 sq. cm. cross-sectional area, containing 12 differential thermocouples. The depth and other general arrangements were the same as described for the 48-couple cell above. Depth of hopcalite was computed from measurements of the volumes of hopcalite

[25] Lamb, A. B., and Larsen, A. T., The Rapid Determination of Carbon Monoxide in Air, *Jour. Amer. Chem. Soc.*, vol. 41, Dec., 1919, pp. 1908–1921.

in a graduate and cell cross-sectional area. The results, presented in Fig. 9, show the best depth of hopcalite to be 3.4 cm. above a 2.2-cm. layer of granular pumice, or 60 per cent of the cell depth; they divide the distance between the thermocouple junctions in the ratio of $^2/_3$ hopcalite and $^1/_3$ pumice. This division between hopcalite and pumice was made in all further experiments with cells of this depth.

Each point of Fig. 9 represents the sensitivity at its respective best rate of flow; these flows were 8.0 liters per minute for the 1.15 cm. depth, 14, $16^1/_2$, 31 and 45 liters per minute. The speed of response of the recorder to changes in CO concentration was always hastened by increasing rates of flow. Using the best depth and best rate, the 12-couple cell responded to a change of CO concentration in 20 sec.; the record of the change was 67 per cent completed at one minute after the change, 90 per cent at 2 min., 95 at $2^3/_4$ min., and the position of precise indication was attained in 5 to 8 min.

Another cell was made 10.8 cm. deep (as compared with 5.63 cm. depth of previous cells), 18.20 cm. cross-sectional area (the same as previous 48-couple cell), and containing 48 differential couples of No. 28 gage (B. & S.) constantan wire and No. 21 copper wire. Tests of this cell with varying depth of hopcalite showed the best depth to be 4.7 cm. However, the cell showed no increased thermoelectric effect when used with its best rate (80 liters per minute), so the shallower cells were mostly employed.

Effect of Increasing Numbers of Thermocouples

A set of cells was made with thermocouples in series of 6, 12, 24, 48 and 96. All cells were the same depth, 5.63 cm.; the cross sections were increased as the number of thermocouples required, and ranged between 2.54 by 2.54 cm. for the 6 couples to 4.60 by 7.14 cm. for the 96 couples. The 6-, 12- and 24-couple units were mounted on single mica cards, the 48 on two cards, and the 96 on three cards. All of these couples were made of silver and constantan wire, respectively, No. 28 and 18 B. & S. gage. Copper wire in place of silver was tried in other cells and appears to be nearly as good, the cells developing almost equal potentials and having nearly equivalent resistances.

The principal characteristics of the series of cells are listed in Table 2. Resistances ranged from 0.274 ohm for the 6 couples to 3.78 ohms for 96 couples. The 6-, 12-, 24- and 48-couple cells developed potentials nearly proportional to the respective numbers of couples, showing about 0.27 millivolt per couple for 1 part of CO per 10,000. This agreement is excellent, in fact, better than generally develops. The 96 couple gave about 0.25 mv. per couple. The decrease in the latter figure is not an unusual deviation as later figures (page 364) will show. It is due probably to irregularities in the flow of gas, or channeling, through various parts of the cross section caused by irregularities of interlocking among the granules. The best rates of gas flow based on the square centimeter unit of cross section also increased with the cross-sectional area of the cell, ranging from 1.71 to 2.74 liters per minute. Reasons for this are obscure, unless channeling is a contributing cause.

Maximum Thermoelectric Effect of Oxidizing Carbon Monoxide in Air

The highest average potential increase attained by oxidizing CO in increments of 1 part per 10,000 parts of air mixture was found at 0.0297 millivolt per thermocouple in the 12-couple cell (see highest point of Fig. 10). The figure 0.0275 millivolt per couple per 1 part CO per 10,000 (see Table 2) may be taken as an average; this is only 66 per cent of the possible potential according to calculations based on the following data:

Item	Value	Authority
Heat of combustion of CO to CO_2	67,960 gram-calories per gram-molecule	Thomsen[26]
Weight of 1 liter of air at 0 deg. cent., 760 mm.	1.2928	Guye[27]
Specific heat of air at 100 deg. cent. and constant pressure	0.2430 calories per gram	Swann[28]
Specific heat of CO_2 at 100 deg. cent. and constant pressure	0.2214 calories per gram	Swann[28]

The data indicates that a temperature increase of 0.966 deg. cent is possible due to oxidation of 1 part of CO in 10,000 parts of air gas mixture at 100 deg. cent. The average increase attained as determined with the thermocouples was 0.635 deg.

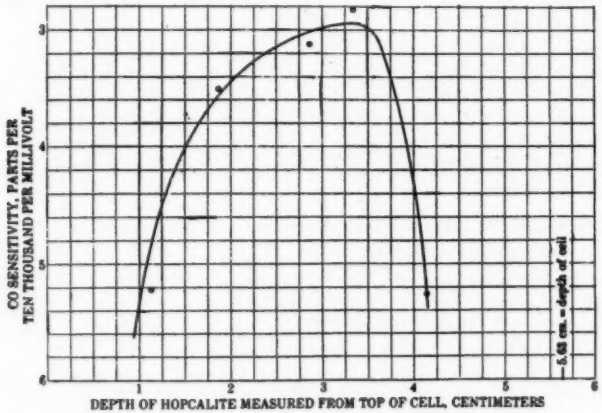

FIG. 9. EFFECT OF VARIOUS DEPTHS OF HOPCALITE ON SENSITIVITY OF CELL CONTAINING 12 DIFFERENTIAL THERMOCOUPLES. GRANULAR PUMICE WAS USED TO FILL THE CELL SPACE REMAINING VACANT AFTER ADDING THE HOPCALITE

TABLE 2. CHARACTERISTICS OF CELLS CONTAINING DIFFERENT NUMBERS OF THERMOCOUPLES

Depth of cells, 5.63 cm. Thermocouples, No. 28 (B. & S. gage) silver and No. 18 constantan wires. Thermo-junctions were soldered, and hot and cold junctions were set, respectively, 0.74 cm. from top and bottom of cell, spacing junctions 4.15 cm. apart. Hopcalite layers at top of cells were 3.4 cm. deep, which includes 2/3 of distance between thermo-junctions. Each couple develops 0.0433 mv. per deg. cent. between 100 deg. and 190 deg.

Number of differential thermocouples	Resistance of couples and leads, ohms	Cross sectional area of cell, sq. cm.	Best rate of gas flow liters per minute		Potential developed by 1 part CO per 10,000 parts air at best flow rate, millivolts	
			Per cell	Per sq. cm.	Per cell	Per couple
6	0.274	6.45	11	1.71	0.160	0.0267
12	0.492	12.90	29	2.25	0.325	0.0271
24	0.985	14.52	33	2.27	0.660	0.0275
48	1.97	18.20	46	2.53	1.30	0.0271
96	3.78	32.90	90	2.74	2.39	0.0249

[26] Thomsen, J., Thermochemistry, p. 232, Longmans, Green, & Co., New York, 1908.
[27] Guye, P. A., Sur les Variations de la Densite de l'Air, et la Loi de Loomis-Morley, *Jour. de Chim. Phys.*, vol. 15, 1917, pp. 561–576.
[28] Swann, W. F. G., On the Specific Heats of Air and Carbon Dioxide at Atmospheric Pressure by the Continuous Electric Method at 20 Deg. Cent. and 100 Deg., *Trans. Roy. Soc.*, vol. 210, 1911, pp. 199–238.

cent. The maximum efficiency attained in any experiment with thermocouples was 70.5 per cent, indicating a 0.680 deg. cent. rise due to 1 part CO per 10,000.

One couple was found to develop an average of 0.0275 millivolt due to 1 part CO per 10,000 and the couples gave a potential of 0.0433 mv. per deg. cent., therefore

$0.0433 \times 0.9656 = 0.0418$ mv. from 1 part CO per 10,000, theoretically possible.

$0.0275 \div 0.0418 \times 100 = 65.8$ per cent of the theoretically possible potential which was on the average attained by the cells.

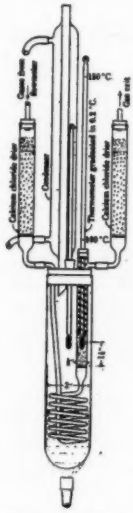

FIG. 10. A CARBON MONOXIDE INDICATOR WITH HOPCALITE AND THERMOMETER

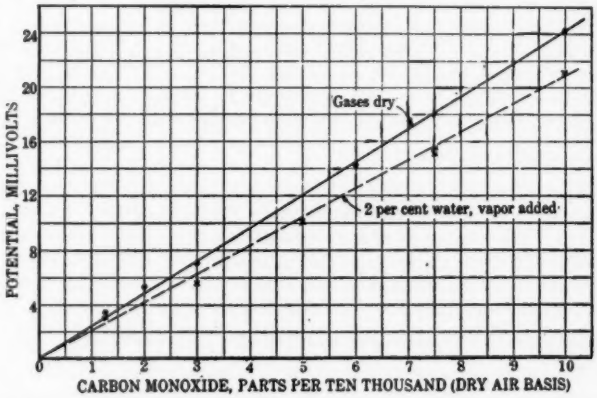

FIG. 11. GRAPH SHOWING LOWERED POTENTIALS DEVELOPED BY THE 96-COUPLE CELL WHEN THE GASES ARE MOISTENED WITH WATER VAPOR AT 15.8 MM. PRESSURE (ABOUT 2 PER CENT BY VOLUME)

And the thermocouples indicate

$0.0275 \div 0.0433 = 0.635$ deg. cent. average rise in temperature of gases due to 1 part of CO per 10,000 parts.

The maximum efficiency attained in any experiment was 70.5 per cent, indicating a 0.680 deg. cent. rise due to 1 part CO per 10,000.

Inability of the cell to indicate a higher temperature difference between the hot and cold junctions of the thermocouples may be due to conduction of heat along the wires or adjacent parts of the cell from the reaction zone to the cold junctions. The cells are insulated laterally by an air space. It was proved that no considerable amount of heat passed laterally from the cell by surrounding the cell with insulation of 85 per cent magnesia; this insulation did not increase the potentials.

Reproducibility of Cells

The 48-couple cell was refilled four times with hopcalite and pumice in the ratio 60:40, and re-calibrated each time. The best flow and the calibration factors were found as stated in Table 3.

TABLE 3. RESULTS OF CALIBRATION OF CELL WITH 48 COUPLES REFILLED FOUR TIMES

Filling of cell, no.	Best rate of flow, liters per minute	Concentration of CO producing 1 mv. potential taken from calibration graph, parts per 10,000	Potential produced in 48 differential couples, by 1 part of CO in 10,000, millivolts
1	42	0.83	1.21
2	43	0.80	1.25
3	44	0.77	1.30
4	46	0.91	1.10
Average	44	0.83	1.21

The maximum CO deviation from the average is less than 10 per cent. This indicates that cells may be refilled repeatedly with ordinary care in proportionating the hopcalite and pumice, and if used with an average calibration of 1.21 millivolts per 48 couples (0.025 mv. per couple) for 1 part CO per 10,000, the error should not exceed 10 per cent of the indicated CO. It is best, however, to recalibrate for each cell filling, which will reduce the relative errors to about 5 per cent or less.

Deterioration of Hopcalite

The thermoelectric cells heretofore were used only for short periods of testing. However, a hopcalite and thermometer arrangement for indicating CO, shown in Fig. 10, was employed as a guide through an extended series of tests. No exact record was kept of the total time the indicator was used, but it amounted to 3 to 7 hrs. on each day when tests were conducted, over a period of months. The instrument was recalibrated several times during this period.

Description of a Thermometer and Hopcalite Indicator for CO

The indicator consists essentially of a thermometer with the bulb inserted into a layer of hopcalite held in a tube through which air with admixed CO passes. The tube is surrounded by a steam bath in glass container, heated by a flame; a reflux condenser is attached and a second thermometer has its bulb in the steam bath to indicate any temperature changes due to the barometric pressure. The air flow was measured through a flow meter, then passed through a glass coil preheater before going to the hopcalite. A guard tube of calcium chloride was interposed in the gas stream before the hopcalite and another after it, to prevent entrance of water vapor. The writers first saw this type of apparatus constructed by R. P. Mase.

Gas was passed at the rate of 4 liters per minute, but later it was found for a subsequent filling that $7^1/_4$ liters per minute was best rate. Calibrations at intervals showed decrease in sensitivity due to deterioration of hopcalite as follows:

TABLE 4. DECREASE IN SENSITIVITY OF CO INDICATOR USED WITH UNPURIFIED ROOM AIR CONTAINING CARBON MONOXIDE

Date calibrated, 1923	CO per deg. cent. rise of thermometer, parts per 10,000	Sensitivity, deg. cent per 1 part CO per 10,000
April 9	1.38	0.72*
May 11	2.15	0.47
July 31	3.50	0.29
September 8	3.73	0.27
September 28	4.00	0.25

* This figure is 0.04 deg. cent. greater than the greatest temperature increment determined with thermocouples and the corresponding thermal efficiency is 74.7 per cent.

The sensitivity decreased from 0.72 deg. cent. for 1 part CO per 10,000 to 0.25 deg., or $^2/_3$ in $5^1/_2$ mos. Deterioration of the hopcalite is undoubtedly due to the action of impurities in the air which it absorbs or catches, such as oil vapors or droplets from the air pumps, dusts and smoke particles, ammonia and acid gases such as sulphur dioxide. It was found that a gas purifier of sulphuric acid, soda-lime, activated charcoal, absorbent cotton filters and calcium chloride removed the deleterious components without perceptibly affecting the passage of the carbon monoxide.

Effect of Moisture

That moisture inhibits the action of hopcalite is well known.[29] Its effect on the accuracy of the recorder was found by passing alternately moistened and dry air with CO through a cell which had first been calibrated with dry gases. The water

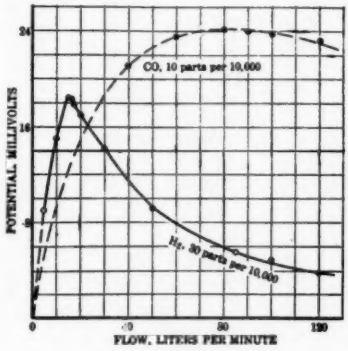

FIG. 12. POTENTIALS DEVELOPED BY 96-COUPLE CELL WITH VARIOUS FLOW RATES OF DRY AIR CONTAINING 30 PARTS PER 10,000 OF HYDROGEN OR 10 PARTS PER 10,000 OF CARBON MONOXIDE

vapor was kept at uniform tension of 15.8 mm. of mercury (equivalent to 91 per cent relative humidity at 20 deg. cent., and constituting about 2 per cent by volume of the resultant humid gas). Fig. 11 shows the effects of the water vapor upon the cell of 24 couples; the respective potentials are lowered about 14 per cent. The gases in these tests entered the cell at the temperature of 100 deg. cent. At lower temperatures the effect of water vapor on hopcalite is accentuated. It was found that the cell recovered fully its original (dry gas) sensitivity in 1 or 2 minutes when the moist gas was followed by dry gas.

Gases passing into the recorder should, for accurate analysis, be free of moisture.

Effect of Hydrogen

The gas purifying system of sulphuric acid, activated charcoal, caustic, absorbent cotton filters and calcium chloride, removes all of the gases or vapors which can impair the hopcalite or vitiate the CO records, with the possible exception of hydrogen. The action of hydrogen was, therefore, investigated. A statement had been made previously that dry hydrogen (90 per cent) mixed with air (10 per cent), and passed through hopcalite at room temperature, showed "no considerable oxida-

[29] Lamb, A. B., Bray, W. C., and Frazer, J. C. W., The Removal of Carbon Monoxide from Air, *Ind. Eng. Chem.*, vol. 12, March, 1920, pp. 215–221.
Katz, S. H., Bloomfield, J. J., and Fieldner, A. C., The Universal and the Fireman's Gas Masks, *Tech. Paper* 300, Bureau of Mines, 1923, 22 pp.

TABLE 5. ERRORS OF ANALYSIS OF CO IN AIR DUE TO PRESENCE OF H_2 IN DIFFERENT PROPORTIONS

CO present, parts per 10,000	Hydrogen, parts per 10,000	Errors: Excess CO indicated, parts per 10,000	Errors: Percentage based on actual CO
Ratio of CO:H_2 = 1:0.1 by volume			
1	0.1	0.014	1.4
2	0.2	0.028	1.4
4	0.4	0.060	1.5
6	0.6	0.096	1.6
8	0.8	0.14	1.8
10	1.0	0.19	1.9
15	1.5	0.35	2.3
20	2.0	0.56	2.8
25	2.5	0.80	3.2
Ratio = 1:0.2			
1	0.2	0.021	2.1
2	0.4	0.044	2.2
4	0.8	0.10	2.5
6	1.2	0.17	2.8
8	1.6	0.25	3.1
10	2.0	0.35	3.5
15	3.0	0.66	4.4
20	4.0	1.06	5.3
25	5.0	1.58	6.3
Ratio = 1:0.4			
1	0.4	0.034	3.4
2	0.8	0.074	3.7
4	1.6	0.18	4.4
6	2.4	0.30	5.0
8	3.2	0.46	5.7
10	4.0	0.64	6.4
15	6.0	1.25	8.3
20	8.0	2.0	10.2
25	10.0	3.1	12.2
Ratio = 1:0.6			
1	0.6	0.058	5.8
2	1.2	0.12	6.1
4	2.4	0.27	6.8
6	3.6	0.46	7.6
8	4.8	0.33	8.4
10	6.0	0.93	9.3
15	9.0	1.8	11.8
20	12.0	2.9	14.4
25	15.0	4.3	17.3
Ratio = 1:1.0			
1	1	0.09	9.0
2	2	0.19	9.6
4	4	0.43	10.7
6	6	0.71	11.9
8	8	1.1	13.2
10	10	1.5	14.6
15	15	2.7	18.3
20	20	4.5	22.3
25	25	6.6	26.4
Ratio = 1:1.5			
1	1.5	0.13	13.1
2	3.0	0.41	13.8
4	6.0	0.61	15.3
6	9.0	1.0	16.9
8	12.0	1.5	18.6
10	15.0	2.1	20.5
15	22.5	3.8	25.5
20	30.0	6.2	31.0
25	37.5	....	...
Ratio = 1:2			
1	2	0.18	18.0
2	4	0.38	18.9
4	8	0.82	20.6
6	12	1.4	22.5
8	16	2.0	24.4
10	20	2.6	26.3
15	30	4.7	31.8
20	40	7.8	38.9
25	50	....	...

tion of hydrogen," but when "the temperature of the affluent gases was raised to about 60 deg. or 70 deg., rapid oxidation of the hydrogen set in."[30]

Hydrogen Alone in Air

Fig. 12 shows the potentials developed by the 96-couple cell when dry air containing hydrogen at dilution of 30 parts per 10,000 was passed through it at various rates of flow, also when CO at 10 parts per 10,000 was passed through. The hydrogen developed maximum potential of 18.4 millivolts at 15 liters per minute flow, whereas the CO developed a maximum of 24.1 millivolts at about 85 liters per minute flow. At 85 liters flow the hydrogen gave only 5.5 millivolts or about 0.183 millivolts per 1 part per 10,000. Thus the effect due to hydrogen alone in air is

[30] Lamb, A. B., Scalione, C. C., and Edgar, G., The Preferential Catalytic Combustion of Carbon Monoxide in Hydrogen, *Jour. Amer. Chem. Soc.*, vol. 44, April, 1922, pp. 738–757.

only about 7.6 per cent of that of the equal partial volume of CO when both are passed at the best flow rate for the carbon monoxide.

Calibration of the 96-couple cell with various concentrations of hydrogen in air up to 50 parts per 10,000 at 85 liters per minute flow (best rate for CO) showed potentials increasing nearly uniformly with concentration. A similar calibration at 15 liters per minute (best rate for H_2) gave nearly uniform potential increases up to concentrations of 20 parts H_2 per 10,000, after which proportionally higher potentials appeared.

Hydrogen and Carbon Monoxide in Air

When mixtures of H_2, CO and air were passed through the cell of 24 couples, potentials were developed as indicated in Fig. 13. This figure shows that a given

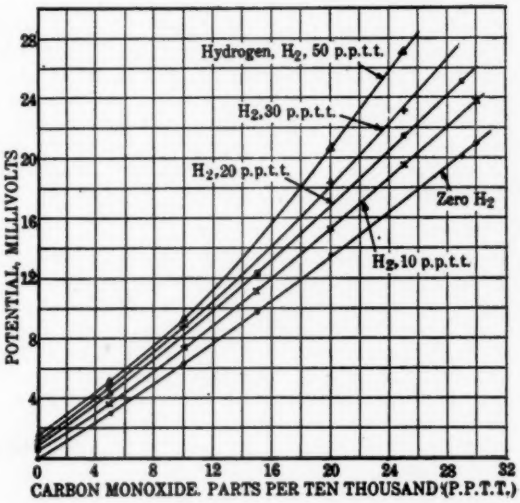

FIG. 13. POTENTIALS DEVELOPED BY 24-COUPLE CELL WITH MIXTURES OF CARBON MONOXIDE AND HYDROGEN IN AIR, PASSING AT RATE OF 33 LITERS PER MINUTE (BEST RATE FOR CARBON MONOXIDE)

concentration of H_2 causes a greater increase in potentials when the CO concentration is high than when it is low. This must be due to the effect of increased temperature generated by the CO, causing more hydrogen oxidation. Carbon monoxide and hydrogen are evolved with automobile exhaust gas in average volume ratio[31] of 1:0.4. The potentials generated in the 24-couple cell by air containing various quantities of CO and H_2 in 1:0.4 ratio (2.5 volumes CO to 1 volume H_2) were taken from Fig. 13 and are shown in Fig. 14, together with the calibration in absence of hydrogen. (This was done graphically by drawing equipotential lines, as indicated by points taken from Fig. 13, on coordinates with concentrations of CO as abscissae and concentrations of H_2 as ordinates, drawing thereon the line indicating CO and H_2 in 1:0.4 ratio and taking from the graph the concentrations of CO and H_2 in ratio 1:0.4, intersecting the various potential lines.) Curves similar to Fig. 14 were drawn, for CO-H_2 mixtures in other ratios, and errors of CO analysis due to the presence of H_2 were taken from them. The results are assembled in Table 5.

[31] Jones, G. W., and Fieldner, A. C., Gasoline Saved on Government Trucks by Adjusting Carburetors by Exhaust Gas Analysis, Reports of Investigations No. 2487, Bureau of Mines, June, 1923, 13 pp.

According to Table 5 the errors of CO analysis, due to the presence of hydrogen in the volume ratio of CO:H_2 = 1:0.4, range from about 3.4 to 5 per cent of the actual CO when the latter is less than 6 parts per 10,000. Such errors may thus occur in analyses of atmosphere in vehicular tunnels. They can be eliminated by calibrating the recorder for CO in presence of H_2 in 1:0.4 ratio, but as the errors are small and are on the side of safety, it is not essential to do so. At higher concentration of the gases in the same ratio the errors are augmented somewhat; in gases of lesser hydrogen-CO ratio, the errors are smaller. Even with hydrogen twice the concentration of the CO, and high concentration of 40 parts per 10,000, the error amounts only to about 39 per cent based on the actual CO; even this error may not be excessive for determinations in some circumstances, if no better determinations are possible.

Recorder for Small Proportions of Carbon Monoxide in Hydrogen

A cell kept in an environment of 25 deg. cent. was not affected by passage of 50 parts per 10,000 (0.5 per cent) of hydrogen in air, whereas at 25 deg. cent., CO in air (passed at its 100 deg. cent., best flow rate) exerted an effect on the recorder about $^1/_3$ as great as at 100 deg. The presence of small quantities of CO admixed with relatively large quantities of hydrogen, as for instance in the hydrogen used for synthetic ammonia production, may thus be recorded by immersing the cell and adjoined gas pipes in a thermostat kept at 25 deg., and passing through the cell the gases admixed with a small proportion of air.

A Hydrogen Recorder

On the other hand, by operating the recorder at 100 deg. cent. and at the best rate of flow for hydrogen, it can be made to record small quantities of hydrogen in air; when recording hydrogen, carbon monoxide should preferably be absent. However, two instruments may be operated in parallel when both gases are present, one at low temperature and one at high, to record the effects of CO alone and of CO plus H_2. The H_2 can then be estimated by differences. Or the CO can be determined and eliminated entirely by oxidation at low temperatures, then the residual hydrogen determined in an environment of higher temperatures.

The maximum thermoelectric effect of hydrogen in air was calculated from data on page 361 together with the following:

Item	Value	Authority
Heat of combustion of H_2 to H_2O at 18 deg. cent.	68380 gram-calories per gram.	Roth[32]
Heat of vaporization of water at 100 deg. cent. and 1 atmosphere pressure	538.9 calories per gram	Carlton-Sutton[33]
Specific heat of steam at 1 kg. per cm.^{2} (99.1 deg. cent. = temperature of saturation)	0.486 calories per gram at 99.1 deg. cent.	Knoblauch and Raisch[34]
Specific heat of liquid water	0.481 at 110 deg. cent Taken as 1.00 calorie per gram for the temperature range 18 deg. cent. to 100 deg. cent.	

The calculation shows 0.813 deg. cent., as the maximum theoretical increase in

[32] Roth, W. A., Die Bildingswarme des Wassers, *Zeit. für Electrochem.*, vol. 26, July, 1920, pp. 288–291.
[33] Carlton-Sutton, T., A Determination of the Heat of Vaporization of Water at 100 Deg. Cent. and One Atmosphere Pressure in Terms of the Mean Calorie, *Proc. Roy. Soc.*, vol. 93, 1917, pp. 155–176.
[34] Landolt-Bornstein-Roth, *Physikalisch-Chemische Tabellen*, 1923, p. 1276.

temperature of gases due to oxidation at 100 deg. cent. of H_2 in air when at concentration of 1 part per 10,000.

As compared with this, calculations based on the potential measurements and calibration of the thermocouples for temperature effects show an effective temperature rise of only 0.120 deg. cent. per 1 part H_2 per 10,000 or 14.8 per cent of the theoretically possible effect. An analysis of the gases escaping from the apparatus when passed at the best rate for hydrogen showed the following:

Hydrogen entering = 50 parts per 10,000 (by dilution apparatus), and hydrogen

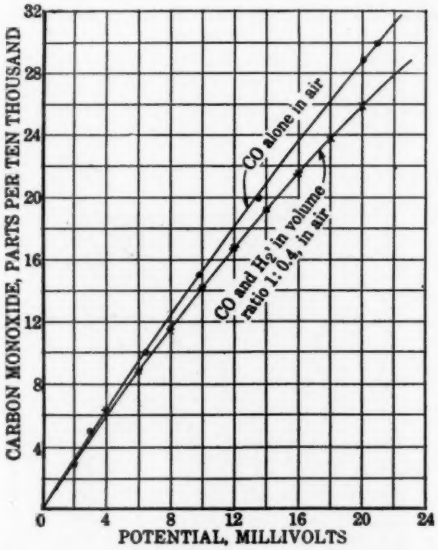

FIG. 14. POTENTIALS GENERATED IN 24-COUPLE CELL BY CARBON MONOXIDE ALONE IN AIR AND BY AIR CONTAINING CARBON MONOXIDE AND HYDROGEN IN VOLUME RATIO OF 1:0.4; RATE OF FLOW, 33 LITERS PER MINUTE, BEST RATE FOR CARBON MONOXIDE

leaving = 43 ± 2 parts per 10,000 (by Haldane analysis). Thus only 14 per cent of the hydrogen was oxidized.

Operating the cell in an environment of higher temperature, 200 or 300 deg. cent., would increase the precision of the recorder in determining hydrogen alone in air.

Effect of Carbon Dioxide

When carbon dioxide gas (CO_2) is present, some of it may be removed by the soda-lime in the canister for purifying the gases, but the soda-lime is not very effective in restraining carbon dioxide and most of it passes through with the air and CO. Mixtures of CO and air with added CO_2 up to 8 per cent were tried in the recorder with 96 thermocouples and temperature of 100 deg. cent. The increasing CO_2 has a linear, decreasing effect on the electric potentials generated by the CO,

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compared to equal CO concentrations in absence of CO_2; but the decrease was small, potentials decreased only 0.60 per cent for each per cent of CO_2 present.

Calculations based on the thermo-chemical data indicate that the decrease in potential, due only to the greater heat capacity of CO_2 per unit volume, is 0.48 per cent for 1 per cent of CO_2. The 0.12 per cent difference may be due to mass action of the CO_2 in opposing the oxidation of CO or to CO adsorbed on the hopcalite preventing some of the catalytic action. Lamb and Vail[25] found a similar but much greater effect of adsorbed CO_2 upon the action of hopcalite at 25 deg. The very small effects of the CO_2 at 100 deg. cent. may be ignored in most practical applications of the CO recorder. Should it be desirable in some instances

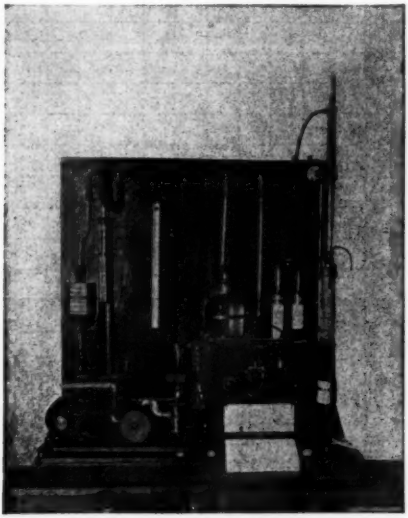

FIG. 15. A CARBON MONOXIDE RECORDER CONSTRUCTED OF GLASS TUBING

to eliminate the effects of the CO_2, a more effective absorbent for it may be included in the gas purifying train.

PERFORMANCE OF CO RECORDERS DURING EXTENDED USE

CO Records from Exhaust Gases of a Gasoline Engine

A CO recorder was operated through a period of 6 mos. in connection with physiological tests of gasoline engine exhaust gases. Fresh air diluted the exhausts until CO concentrations approximated 1 to 4 parts in 10,000. The gases were then passed through a chamber where the CO was recorded during all test periods lasting up to seven or more hours per working day.

This recorder is shown in Fig. 15. All tubes were of glass connected with rubber nipples, and the parts were assembled on a wooden frame designed to set on a table

[25] Lamb, A. B., and Vail, W. E., The Effect of Water and of Carbon Dioxide on the Catalytic Oxidation of Carbon Monoxide and Hydrogen by Oxygen, *J. A. C. S.*, vol. 47, Jan., 1925, pp. 123–142.

or bench. The thermocouples were a series of 6 pairs set lengthwise along a diametrical plane in a glass tube holding pumice and hopcalite. Except for the thermocouple construction in the cell, the glass parts and connections were similar to those of the thermometer-and-hopcalite indicator for carbon monoxide.

The air in the chamber was sometimes sampled, simultaneously with the operation of the recorder, continuously, and at uniform rate to obtain composite samples. Two such samples were taken each day, one in the morning and one in the afternoon. They were analyzed by the blood-pyrotannic acid method, accurate to about $^1/_2$ part per 10,000.[36] The average concentration of CO was determined from

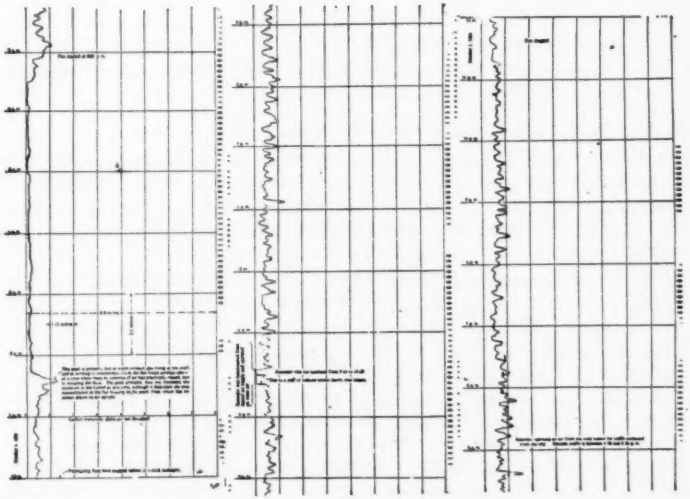

FIG. 16. CARBON MONOXIDE RECORD IN NORTH HALF OF WEST TUBE, LIBERTY TUNNELS, FOR OCTOBER 1, 1924. THIS TUBE CONDUCTS THE SOUTHWARD TRAFFIC, OUTBOUND FROM PITTSBURGH

TABLE 6. ACCURACY OF CO RECORDER WITH 6 COUPLES, OVER A PERIOD OF 6 MONTHS, BASED ON RESULTS OF CO ANALYSES BY THE BLOOD-PYROTANNIC ACID METHOD

Concentrations of CO in air ranged up to about 4 parts per 10,000

Month, 1924	Total number of comparisons	Deviations of recorder, parts of CO per 10,000					
		Positive			Negative		
		Number	Maximum	Average	Number	Maximum	Average
January	7	5	1.2	0.6	2	0.4	0.2
February	18	14	1.5	0.5	4	0.5	0.2
March	31	27	1.5	0.6	4	1.1	0.6
April	28	22	1.6	0.5	6	1.2	0.4
May	31	17	1.1	0.4	14	0.6	0.3
June	29	19	1.3	0.5	10	1.1	0.4
July	25	20	1.7	0.7	5	1.4	0.5
		General average		0.54			0.37

[36] Sayers, R. R., Yant, W. P., and Jones, G. W., The Pyrotannic Acid Method for the Quantitative Determination of Carbon Monoxide in Blood and Air, Bureau of Mines, *Tech. Paper*, 373, 1925, 18 pp.

the recorder graph by integrating the time-concentration area and dividing by the time. A statement of the accuracy of the recorder based on the pyrotannic acid analysis for CO is given in Table 6.

Most of the discrepancies stated in Table 6 indicate slightly higher CO as determined by the recorder. Although a few individual determinations gave rather large discrepancies, there are several causes, which are not due to the recorder, possibly contributing to these: these causes may be incomplete mixing of gases in the chamber, accidental irregularities in rate of sampling, and errors of analysis. The average deviations, positive and negative, hardly exceed the analytical errors of the blood-pyrotannic acid method. However, the results are especially interesting because they indicate no decrease in sensitivity of the recorder during a period of usage exceeding 6 months.

Throughout the tests the chemists, engaged in the physiological experiments, were guided principally by the analyses of the recorder.

Operation of a CO Recorder at the Liberty Tunnels

The recorder shown in Fig. 1 was operated continuously at the Liberty tunnels since August 1, 1924, and at the present time (January 1, 1925) it is still operating without apparent change in sensitivity, and entirely satisfactorily in other respects. The record for the north half of West Tunnel, Wednesday, October 1, is presented as typical in Fig. 16.

The fans are operated from about 7 o'clock in the morning till nearly midnight. As long as the fans operate the gas sample taken by the recorder is truly representative of tunnel conditions. From midnight through the early morning hours the tunnels have natural ventilation. During these hours ventilation may be caused by the wind, by differences in barometric pressure, or by the traffic in the tunnel.[17] On the other hand, mass movements of air may cease entirely on quiet nights, at intervals when there is no traffic. At times of natural ventilation, movement of air in the ventilating shafts, in the air passageways in the fan-house above the tunnels, and in the stack vents, may be either upward, downward or without movement. Fig. 16 shows a peak at 1:35 A.M. of about 1.3 parts of CO per 10,000. This is probably due to warm exhaust gas rising in the ventilating shaft, and so tending to accumulate some CO in the fan-house airways above. Mass movements of air through the fan-house must have ceased. Hence this peak probably does not represent conditions in the tunnel at the time, although it indicates the true concentration of CO in the fan enclosure at the point from which the recorder draws its air sample. After this peak the CO dropped rather abruptly and continued at about 0.1 to 0.3 part per 10,000 until 6:30 A.M. This probably represents actual conditions in the tunnel with a natural ventilating current carrying tunnel air upward through the fan-house to the discharge stacks; however, no observations on the ventilation were made then to ascertain this.

About 6:30 A.M. there was a sharp increase in the CO, the fans were started at 50 r.p.m. about 7 o'clock and apparently drew out some accumulated CO because the concentration rose to about 1.1 parts per 10,000 and then decreased. At 9:40 the recorder was stopped to clean and oil the mechanism and to supply ink and about 3 lbs. of fresh sulphuric acid; the attention of a man for 10 to 30 min. is needed daily for these duties. During most of the day the concentration ranged around 0.5 and occasionally rose to about 1.0 part per 10,000. Between 4:30 and 6:30 P.M. the traffic peak occurs in the west tunnel which is used by the traffic outbound from

[17] Fieldner, A. C., Yant, W. P., and Satler, Jr., L. L., Natural Ventilation in the Liberty Tunnels, *Eng. News-Record*, vol 93, August 21, 1924, pp. 290–291.

Pittsburgh. The recorder shows a maximum for the day about 1.6 parts per 10,000, and between 5 and 6 P.M. the CO ranged around 1.0 part per 10,000. Thereafter the concentration was mostly below 1.0 part, ending with 0.4 part per 10,000 at midnight.

All the records show that the ventilation has been more than ample since 4 parts CO per 10,000 parts of air is a tolerable maximum for one hour's exposure. At no time has the CO in this tunnel exceeded the 4 parts, since installing the recorder, although it approached closely during a few short intervals, then soon decreased.

Other Applications of the Recorder

The recorder previously described was tried only with carbon monoxide, and hydrogen in air, but the thermoelectric method of analysis is by no means limited to these gases. Hopcalite or other catalyzers of oxidation can act on many combustible gases in air or oxygen, either at the temperatures heretofore employed or else at higher temperatures. The heat of oxidation of any combustible gas in considerable dilution in air or oxygen or *vice versa* can thus be employed as a means of recording the concentrations. Temperatures of the environment about the cell may be increased by surrounding the cell and preheating coils with the saturated vapor of a liquid of higher boiling point than water or by an electrically heated or flame-heated, solid liquid, or gaseous medium with thermostatic control. At higher cell temperatures, binary mixtures of air and methane might be analyzed, or air with any of the hydrocarbon gases or vapors such as gasoline, acetylene or benzene, and vapors of many other organic compounds such as alcohol, aniline, acetone, ether formaldehyde and many more. Even the gaseous compounds of sulphur or phosphorus might be determined by the method, provided that a suitable purifying system and catalyst is employed.

The apparatus may be used to record the progress of some chemical reactions that involve the removal or addition of a gaseous component, provided that carbon monoxide can, without influencing the reaction, be introduced in uniform proportion into the gases prior to the reaction. For instance: the ammonium carbonate leaching process for copper requires oxidizing with air a solution of cuprous ammonium carbonate in water to cupric ammonium carbonate; and it is necessary for efficient oxidation that the air be supplied in quantity to maintain about 50 per cent excess oxygen under various conditions of volume and concentration.[38] If carbon monoxide is introduced into the air stream, say in uniform ratio of 5 volumes of CO to 10,000 volumes of air, a recorder arranged for highest sensitivity might be made to indicate the oxygen consumption by the increase in concentration of the CO as oxygen decreases. Similar applications may be made in other gas reactions.

DISCUSSION

ROBERT S. ARNOLD: May I ask Mr. Katz if he has ever experimented in connection with garages, with carbon monoxide present in garages, and if so, where he has found the carbon monoxide located, at what level in the garage, in various weather conditions.

E. S. HALLETT: I would like to ask if that has been set up in other buildings, and whether it will take measures of the carbon monoxide that will be generated in the outdoor air, to the street, filled with automobiles. I am curious to know how

[38] Benedict, C. H., and Kenny, H. C., Ammonia Leaching of Calumet and Hecla Tailings, *Trans. Amer. Inst. Min. & Met. Engrs.*, vol. 70, 1924, pp. 595–610.

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much carbon monoxide would be present on the sidewalk when I am walking along the street that is filled entirely with running automobiles.

S. H. KATZ: The carbon monoxide recorder has not yet been used to determine CO in garages. We have had considerable correspondence on the subject and it is very probable that the apparatus will be used for that purpose in the future. However, we have no commercial arrangements for the apparatus at this time. The status in this respect is: I have been permitted to obtain a patent which was granted March 30, 1926; nothing further has developed. There were a few apparatus made according to our plans and specifications, which are in the hands of gas companies, who are using them for experiments with gas heated appliances and stoves.

If recorders are installed at garages, they can indicate the carbon monoxide and warn when it reaches dangerous concentrations. They should, of course, be under the supervision of competent persons.

Regarding the levels in garages at which carbon monoxide will exist, the exhaust gases from automobiles are hot, and while carbon monoxide alone has about the same density as air when at the same temperatures, yet the warm mixture of exhaust gases, carbon dioxide, hydrogen, carbon monoxide, nitrogen, tend to rise and so higher concentrations of carbon monoxide usually exist at higher levels.

The carbon monoxide in street air has received attention in the technical literature. Drs. Henderson and Haggard have a paper in the *Journal of the American Medical Assn.*, Aug. 4, 1923, pp. 385–91. Some persons have appeared alarmed about the carbon monoxide existing in city streets. In my opinion we should not be scared. Persons close to the exhausts of the cars, for instance, traffic officers, may sometimes be slightly affected, but I believe the occasions are seldom. People on the sidewalk I do not think feel the effects, excepting odors. However, we have little information and the above statements must be taken as unsupported opinions. It would be relatively easy to determine the concentrations of carbon monoxide by means of the recorder at some suspected points in cities and to obtain continuous records, say, for periods of a week.

R. S. ARNOLD: There is one other point that I want to bring up. Mr. Katz, I understood you to say that the carbon monoxide is probably located at higher levels in the garage. From information I can gather on ventilation in garages, it seems that the main trouble is near the floor line with carbon monoxide. For instance, mechanics working near the floor seem to be overcome quicker by carbon monoxide, and other people that may be walking around in the garage, where they are breathing the air at higher levels in the garage are all right.

How do you account for that?

S. H. KATZ: Of course, the concentrations are not uniform unless the air and gases are thoroughly mixed. Localized high concentrations of CO can occur near the floor, especially in line with, or in the vicinity of an exhaust gas discharge. My statements were based on the experiments in the experimental vehicular tunnel of the Bureau of Mines near Pittsburgh, Pa., operated in cooperation with engineers for the Holland Tunnel under the Hudson River, to obtain data. The results are being published in your JOURNAL. In those tests, automobiles ran around the circular tunnel for periods of one hour. The tunnel was ventilated and samples of the atmosphere were taken at various levels continuously during a period. Some were taken near the floor; some midway up; some at the ceiling. The concentrations on the average were higher above than below. Even with downward ventilation, the carbon monoxide appeared first to rise and then to descend, when cooler. In general the carbon monoxide in automobile exhaust gas does tend to rise.

No. 750

WORK TESTS CONDUCTED IN ATMOSPHERES OF LOW TEMPERATURES IN STILL AND MOVING AIR

By W. J. McConnell[1] (*Non-Member*) and C. P. Yaglou[2] (*Member*)

PREVIOUS articles[3] on the investigative work carried on cooperatively by the American Society of Heating and Ventilating Engineers, the U. S. Bureau of Mines, and the U. S. Public Health Service reported only the studies of the physiological reactions to high temperatures. The object of this paper is to present supplementary results of experiments wherein the subjects perform measurable amounts of work at a constant rate in still and in moving air under ordinary and low temperatures.

The procedure followed contrasted closely with the former studies. Briefly, four male subjects of average size and weight between the ages of 20 and 30, free from physical defects, were selected for the tests. The subjects rested quietly in a primary room of a comfortable temperature for a period of two hours. Rectal and mouth temperatures, and pulse-rate were recorded every half hour. The blood pressure and weight were taken at the end of the rest period. The subjects then entered the conditioned chambers, two into each chamber. The temperature conditions were maintained equally in both chambers, but in one the air was motionless, while in the other the air was kept in motion at the rate of 350 ft. per minute. (After covering the entire field, the subjects changed rooms; those in the still air chamber being transferred to moving air and *vice versa*.) The subjects performed the same work as those of previous experiments which consisted of raising a weight of 40 pounds by means of pulley and rope through a distance of

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[1] Medical Director, Philadelphia Health Council, formerly Surgeon, Bureau of Mines and Past Ass't. Surgeon (R) U. S. Public Health Service.

[2] Instructor, Harvard School of Public Health, formerly Engineer, American Society of Heating and Ventilating Engineers, Research Laboratory.

[3] The Effects of High Temperature and Humidities, by W. J. McConnell, *The Nations' Health*, vol. 4, Oct., 1922, pp. 616–617. Some Physiological Reactions to High Temperatures and Humidities, by W. J. McConnell and F. C. Houghten, Jour. A.S.H.&V.E., Mar., 1923, pp. 131–164. Further Study of Physiological Reactions, by W. J. McConnell, F. C. Houghten and F. M. Phillips, Jour. A.S.H.&V.E., Sept., 1923, pp. 507–514. Air Motion—High Temperature and Various Humidities—Reactions on Human Beings, by W. J. McConnell, F. C. Houghten and C. P. Yaglou, Jour. A.S.H.&V.E., Mar., 1924, pp. 199–224. Basal Metabolism Before and After Exposure to High Temperatures and Various Humidities, by W. J. McConnell and C. P. Yaglou, Reprint No. 977 from the *Public Health Reports*, Dec. 5, 1924, pp. 3075–3088. Work Tests Conducted in Atmospheres of High Temperatures and Various Humidities in Still and Moving Air, by W. J. McConnell and C. P. Yaglou, Jour. A.S.H.&V.E., Jan., 1925, pp. 35–57.

Paper presented at Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, Lexington, Ky., May, 1926.

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5 ft. and repeating the task 75 times during a 5-minute period. They then rested the following 5 min. and again performed the same routine for about $2^1/_2$ hr. The clothing worn during the experiments consisted of light weight trousers, work shirt, socks, and shoes. The subjects were permitted to satisfy their thirst with cold water and kept a record of the amount.

The rectal, mouth, and sometimes the surface temperatures, and changes in the pulse-rate were obtained during the intervals of rest. The blood pressure and body weight were again taken at the end of the test. All symptoms and signs of fatigue were carefully noted.

A representative graph of some of these measurements for a single subject in a given atmospheric condition is shown in Fig. 1.

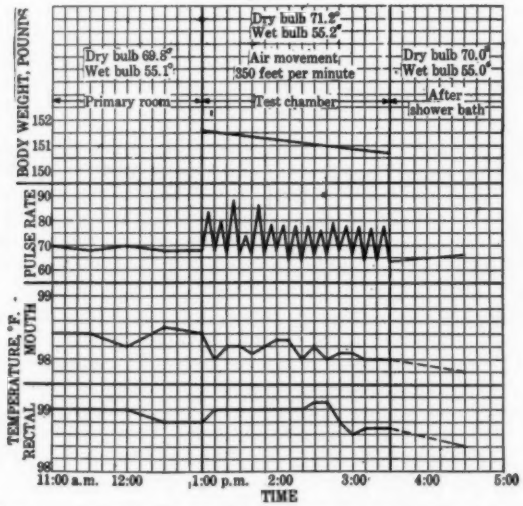

FIG. 1. GRAPH SHOWING MEASUREMENTS FOR SINGLE SUBJECT IN GIVEN ATMOSPHERIC CONDITION

The graph is divided into three sections: The first section shows the initial physiological measurements of the subject taken at half-hour intervals while resting in the primary room. The quantities usually drop, depending upon the previous activities during this period.

The middle section of the graph demonstrates the physiological reactions to work and temperature conditions during the test. Of these the pulse rate is the most fluctuating quantity. The peaks of the pulse-rate graph represent the increase immediately after the completion of work while the low points represent the decrease in frequency at the end of the rest period. It will be noted that the pulse-rate is higher at the beginning of the test, and as the muscular work is continued it attains a somewhat lower value, which is maintained more or less constant at this temperature condition. The initial rise occurs before the muscles concerned

acquire the rhythm of the necessary movements. It is of interest to note that in this experiment with the given temperature condition and work output the pulse-rate always returned to normal or below normal after the 5-min. rest period.

The rectal and mouth temperatures likewise dropped in the course of the experiment. Apparently, this test condition with the air moving at the rate of 350 ft. per minute permitted the subject to lose more heat from his body than the muscular work produced. Undoubtedly the subject could have performed the same amount of work with shorter rest periods without effecting an excess of body

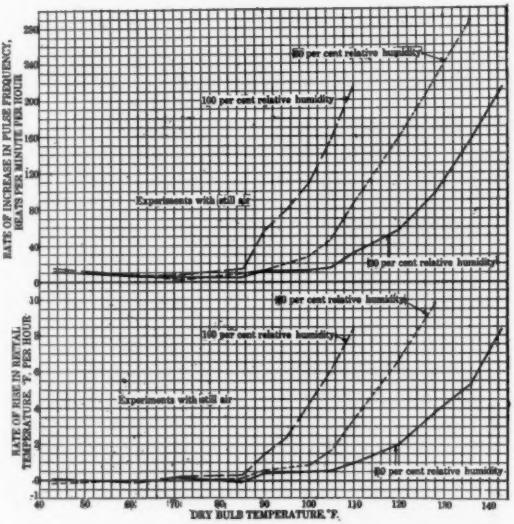
RATE OF INCREASE IN PULSE FREQUENCY, BEATS PER MINUTE PER HOUR
80 per cent relative humidity
100 per cent relative humidity
Experiments with still air
60 per cent relative humidity
RATE OF RISE IN RECTAL TEMPERATURE, °F. PER HOUR
80 per cent relative humidity
100 per cent relative humidity
Experiments with still air
60 per cent relative humidity
DRY BULB TEMPERATURE °F.

FIG. 2. AVERAGE RATE OF RISE IN RECTAL TEMPERATURE AND PULSE FREQUENCY DURING WORK IN STILL AIR

heat. The temperature conditions were pronounced ideal by the subject for this particular rate of work.

The third section of the graph indicates the physiological reactions following the test and shows a further drop in the quantities. Similar results were obtained throughout the entire low-temperature field.

However, when the temperature of the environment approaches the temperature of the body, the loss of bodily heat is interfered with and the physiological reactions increase at an accelerated rate, as described in previous reports and as indicated in Figs. 2 and 3.

Results of Experiments

The experimental data and results in Tables 1 and 2 are for still and moving air respectively, and are so arranged that comparison with previous studies may be made. The headings are self-explanatory and in general indicate the methods of obtaining the results. The number of hours in the chambers include the work

and rest periods of the experiment. The work performed in foot-pounds is obtained by multiplying the number of *pulls* by 200. The rate of rise in rectal temperature is computed by dividing the difference between the initial and final reading by the time consumed during the work period separately for each subject. The average of the four subjects is also shown. In computing the rate of increase in the pulse frequency, the average of the pulse-rates before and after the last 5-min. work period is taken as the average pulse at the end of the test. From this the initial pulse is subtracted to obtain the increase in the pulse-rate for the experiment which, divided by the average time, gives the rate of increase in the

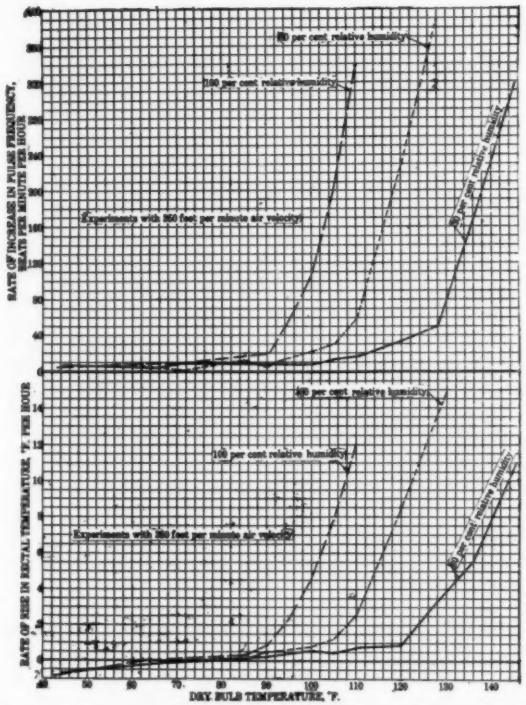
RATE OF INCREASE IN PULSE FREQUENCY, BEATS PER MINUTE PER HOUR
RATE OF RISE IN RECTAL TEMPERATURE, °F. PER HOUR
80 per cent relative humidity
100 per cent relative humidity
Experiments with 350 feet per minute air velocity
80 per cent relative humidity
100 per cent relative humidity
Experiments with 350 feet per minute air velocity
DRY BULB TEMPERATURE, °F.

FIG. 3. AVERAGE RATE OF RISE IN RECTAL TEMPERATURE AND PULSE FREQUENCY DURING WORK IN MOVING AIR

pulse-rate separately for each subject. The last column gives the remarks of the subjects as to the comfort of the atmospheric conditions.

Discussion of Results

It will be observed that the subjects invariably were capable of doing 225,000 foot-pounds of work during the $2^1/_2$-hr. exposure in the low-temperature field. This is about four times the amount of work they were able to perform in a saturated condition at body temperature, and $6^1/_2$ times more work was performed than in a saturated condition of 110 deg. While the same amount of work was

performed in all the experiments presented in this report, the resultant fatigue and degree of comfort at the end of the tests varied considerably, depending upon the atmospheric conditions within the chambers.

The correct evaluation of subjective reactions is a matter of considerable difficulty. It is impossible always to distinguish physical, mental, physiological and psychological types of fatigue or ever to measure exactly the various factors which contribute to their cause. As rest removed the fatigue experienced among the subjects of the experiments no doubt it was physiological in nature, and as factors such as worry, fear, anger, discontent, depression, poor lighting and insufficient air exchange could be discarded, the temperature conditions of the chamber were probably of greater importance than other causes.

As a general rule the subjects complained of fatigue that lasted for several hours following experiments in temperatures above 80 deg. fahr. in still air.

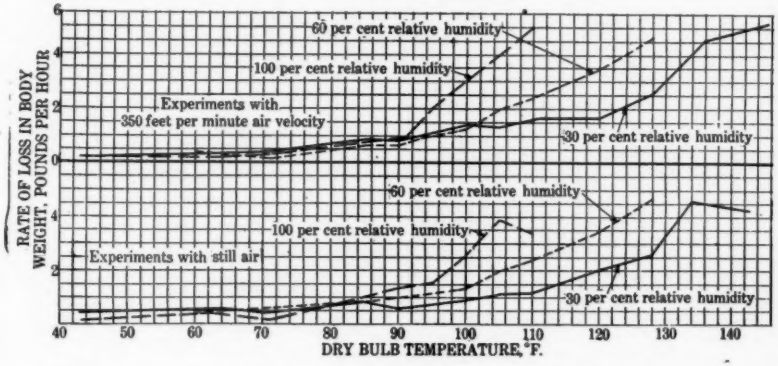

FIG. 4. AVERAGE RATE OF LOSS IN BODY WEIGHT DURING WORK IN STILL AND IN MOVING AIR

With air movement this condition was not reached until the temperature reached well above 80 deg. fahr.

Tables 1 and 2 give the deductions which suggest themselves in the course of this study as regards a comfort zone during work at a given rate of 90,000 foot-pounds per hour with intermittent rest periods. It will be seen that a temperature of 43 deg. fahr. was pronounced as too cold with and without air movement, regardless of humidity, while on the other hand, conditions above 85 deg. fahr. were found to be too warm for comfort.

This indicates that the experiments were conducted above and below the temperature limits of the comfort zone, and that zone must lie somewhere between these two atmospheric conditions. In tests No. 42 and 60*D* the temperature was 60 deg. fahr. and the humidity 60 per cent. With still air this condition was found to be comfortable for three of the subjects and comfortably cool for the fourth. In other words, one of the subjects, while comfortable, preferred a slightly higher temperature rather than a lower one and the others were contented with the conditions. Therefore, we are justified in assuming that this condition must lie at the lower temperature boundary of the comfort zone. The upper boundary of the comfort zone is not so well defined in these experiments, but it appears to

TABLE 1. DATA AND RESULTS

Test No. and Date 1925.	Test Conditions	Subjects	Time Entered Chamber	Time Left Chamber	In Chamber, hours	Rectal Temperature, °F. Initial	Average Time	Total Rise	Rate of Rise per hour	Pulse Initial
42D		W.E. Miller	1:20	3:50	2.50	99.2	2.42	-0.1	-0.04	84
2-24	D.B. 60.0	T.A. Donaghue	1:25	3:55	2.50	99.2	2.42	0.7	0.29	80
	W.B. 52.0								Av.-0.01	
40D	R.H. 60%	W.S. Vineland	1:00	3:30	2.50	99.0	2.42	-0.2	-0.08	72
4-20		C.F. Moore	1:05	3:35	2.50	99.4	2.42	-0.5	-0.21	92
		W. Illig	1:05	3:35		99.3	2.42	-0.7	-0.29	76
43D	D.B. 62.7	T.A. Donaghue	1:00	3:30	2.50	100.6	2.42	-0.3	-0.12	86
2-26	W.B. 53.9									
	R.H. 60%								Av.-0.21	
		W. Illig	1:30	4:20		99.2	2.42	0.4	0.17	90
44D	D.B. 62.5	T.A. Donaghue	1:45	4:15	2.50	99.2	2.42	0.0	0.00	82
	W.B. 52.5									
3-2	R.H. 100%								Av. 0.09	
3-4		W.E. Miller	1:15	3:45		99.2	2.42	0.3	- 0.12	76
45D	D.B. 85.0	T.A. Donaghue	1:20	3:50	2.50	100.2	2.42	0.5	0.21	84
	W.B. 63.5								Av. 0.04	
4-17	R.H. 30%	W.S. Vineland	1:30	4:00	2.50	98.4	2.42	0.2	0.08	68
39D		C.S. Moore	1:35	4:05		99.6	2.42	-0.8	- 0.33	92
3-6		W.E. Miller	1:05	3:35		99.3	2.42	0.7	0.29	96
46D	D.B. 85.5	T.A. Donaghue	1:00	3:30	2.50	100.0	2.42	1.7	0.70	74
	W.B. 65.5								Av. 0.20	
42-D	R.H. 100%	W.S. Vineland	1:30	3:30	2.50	99.0	2.42	0.3	0.12	74
4-24		C.F. Moore	1:05	3:35		99.8	2.42	0.2	0.08	92
3-9		W.E. Miller	1:20	3:50		99.2	2.42	0.0	0.00	70
47D	D.B. 85.0	T.A. Donaghue	1:15	3:45	2.50	99.6	2.42	1.5	0.62	78
	W.B. 74.1								Av. 0.16	
58-D	R.H. 60%	W.S. Vineland	1:00	3:30	2.50	99.4	2.42	0.2	0.08	72
4-15		C.F. Moore	1:05	3:35		100.0	2.42	-0.2	- 0.08	86
		W.S. Vineland	1:10	3:30		99.8	2.42	0.0	0.00	76
48D	D.B. 82.2	T.A. Donaghue	1:05	3:35	2.50	101.0	2.42	0.3	- 0.12	78
	W.B. 62.2									
3-11	R.H. 100%								Av-0.06	
3-10		W.S. Vineland	1:00	3:20		99.0	2.42	0.6	0.25	70
49D	D.B. 70.3	T.A. Donaghue	1:03	3:36	2.50	100.6	2.42	0.0	0.00	72
	W.B. 58.4								Av. 0.12	
54-D	R.H. 39%	A.W. Dickert	1:00	3:30	2.50	98.6	2.42	0.5	0.21	104
4-29		C.F. Moore	1:05	3:35		99.2	2.42	0.1	0.04	84
3-16		W.S. Vineland	1:05	3:35		99.4	2.42	0.4	0.17	70
50D	D.B. 64.2	T.A. Donaghue	1:00	3:30	2.50	100.0	2.42	0.2	0.08	72
	W.B. 48.8								Av. 0.07	
54-D	R.H. 30%	W.E. Miller	1:00	3:30	2.50	99.8	2.42	-0.2	-0.08	98
4-6		C.F. Deasy	1:05	3:35		99.2	2.42	+0.3	0.12	84
3-20		W.E. Miller	10:35	1:05		99.2	2.42	-0.5	-0.21	90
51D	D.B. 70.3	T.A. Donaghue	10:20	1:00	2.50	99.0	2.42	1.3	0.54	78
	W.B. 55.7								Av. 0.01	
56-D	R.H. 39%	W.S. Vineland	1:05	3:35		99.4	2.42	- 0.2	-0.08	76
4-8		C.F. Deasy	1:00	3:30		100.0	2.42	-0.5	-0.21	84
3-27		W.S. Vineland	1:00	3:30		99.2	2.42	0.2	0.08	74
52D	D.B. 71.0	T.A. Donaghue	1:05	3:35	2.50	100.0	2.42	0.6	0.25	72
	W.B. 59.7								Av. 0.15	
57-D	R.H. 95%	H.F. Brubach	1:00	3:30	2.50	100.0	2.42	0.0	0.00	86
4-13		C.F. Moore	1:05	3:35		99.4	2.42	0.6	0.25	100
3-30		W.S. Vineland	1:35	4:05		99.0	2.42	0.6	0.25	88
53-D	D.B. 90.4	T.A. Donaghue	1:30	4:00	2.50	100.3	2.42	0.9	0.37	76
	W.B. 76.0								Av. 0.41	
41-D	R.H. 58%	A.W. Dickert	1:00	3:30	2.50	99.0	2.42	1.2	0.49	118
4-22		C.F. Moore	1:05	3:35		99.0	2.42	1.2	0.49	103
56 D		W.S. Vineland	1:00	3:30	2.50	99.2	2.42	-0.2	-0.08	76
4-10	D.B. 71.1	T.F. Deasy	1:05	3:35	2.50	99.6	2.42	-0.2	-0.08	80
	W.B. 59.8									
55-D	R.H. 51%	T.A. Donaghue	1:00	3:30	2.50	100.0	2.42	-0.2	-0.08	72
4-27		C.F. Moore	1:05	3:35	2.50	98.6	2.42	0.6	0.25	90
									Av.0.0	

lie somewhere between 75 and 80 deg. fahr. with ordinary humidities and in still air.

By far the most comfortable conditions that were considered ideal for the given rate of work are in still air conditions of 70 deg. fahr. with about 40 per cent relative humidity and 71 deg. fahr. with 50 per cent relative humidity. With air movement the temperature values are higher, as shown in the tables.

While these experiments show only a few combinations of temperature, humidity, and air movement conducive to the comfort of workers, it is hoped that the separate investigation into the various equivalent atmospheric conditions, now in progress at the research laboratory of the AMERICAN SOCIETY OF HEATING

OF EXPERIMENTS IN STILL AIR

Pulse Rate in Beats per Min. Final Before Fall	Final After Fall	Average Time	Increase	Rate of Increase	Body Weight in Pounds Initial	Loss	Rate of Loss (lbs. per hr.)	Work Done Total No. of Falls	Total Foot-Pounds	Remarks of Workers as to Temperature Condition
84	120	2:46	36	14.6	138.81	1.31	0.52	1125	225000	Comfortable
80	124	2:46	30	12.2	137.87	1.50	7.60	"	"	"
			Av.	8.8		Av.	0.44			
72	84	2:46	8	1.2	151.50	0.50	0.20	"	"	Comfortably cool.
92	118	2:46	18	6.1	130.31	1.06	0.42	"	"	Comfortable
78	120	2:46	30	12.2	138.16	0.97	0.39	"	"	"
86	124	2:46	28	9.4	139.75	1.25	0.50	"	"	Feel Chilly.
			Av.	10.8		Av.	0.45			
90	120	2:46	40	16.3	140.37	0.56	0.22	"	"	Just right for test.
82	120	2:46	26	10.6	139.87	0.44	0.18	"	"	Cold.
			Av.	13.5		Av.	0.20			
96	130	2:46	12	4.9	133.25	2.06	0.82	"	"	Warm; cooler preferred.
86	114	2:46	18	6.1	139.63	2.44	0.98	"	"	" " "
			Av.	5.0		Av.	0.83			
68	79	2:46	11	4.5	151.37	1.37	0.55	"	"	Warm.
92	112	2:46	11	4.5	129.87	2.37	0.95	"	"	
96	120	2:46	42	17.1	132.13	2.38	0.96	"	"	Too warm.
74	120	146	29	24.0	139.87	3.44	1.38	"	"	" "
			Av.	14.2		Av.	0.98			
74	92	2:46	10	4.1	153.00	1.75	0.70	"	"	" "
92	128	2:46	28	11.4	131.27	2.13	0.88	"	"	" "
70	120	2:46	8	3.3	134.37	2.56	1.00	"	"	Warm; prefer cooler.
88	132	2:46	32	13.0	140.19	2.69	1.08	"	"	" "
			Av.	8.5		Av.	0.83			
72	100	2:46	16	6.5	142.0	2.0	0.80	"	"	Rather warm
86	138	2:46	27	11.0	148.63	1.75	0.43	"	"	
74	100	2:46	14	5.7	151.50	0.75	0.30	"	"	Too Cool.
78	108	2:46	17	6.8	140.75	1.50	0.60	"	"	"
			Av.	6.3		Av.	0.48			
80	104	2:46	22	8.9	152.00	1.19	0.48	"	"	Comfortable.
92	116	2:46	27	11.0	140.31	1.50	0.60	1125	225000	Fairly comfortable.
			Av.	7.4		Av.	0.45			
104	128	2:46	2	0.8	114.25	1.00	0.40	1125	225000	" "
84	116	2:46	22	9.0	139.87	0.75	0.30	"	"	Very comfortable.
70	104	2:46	24	9.5	151.31	1.00	0.40	"	"	Comfortably cool.
72	110	2:46	26	10.6	140.00	1.50	0.60	"	"	" "
			Av.	6.2		Av.	0.54			
98	114	2:46	5	2.0	123.19	1.16	0.46	"	"	Very comfortable.
84	98	2:46	6	2.4	149.25	1.75	0.70	"	"	" "
80	118	2:46	14	5.7	131.87	1.28	0.51	"	"	" "
78	110	2:47	18	7.7	130.56	1.87	0.75	"	"	Ideal temperature.
			Av.	4.8		Av.	0.61			
76	88	2:46	9	3.7	150.24	1.19	0.48	"	"	Comfortable.
84	102	2:46	6	2.4	150.25	1.75	0.70	"	"	Very comfortable.
80	100	2:46	16	5.5	151.56	-0.13	0.05	"	"	Fair.
72	90	108	27	11.0	139.69	1.69	0.68	"	"	Warm.
			Av.	7.0		Av.	0.21			
86	90	2:46	1	0.4	128.0	0.06	0.02	"	"	
100	134	2:46	27	11.0	137.87	3.19	0.78	"	"	Sedimr but not 2% tiresome.
88	96	124	39	15.8	151.75	2.06	0.82	"	"	Too warm.
76	100	124	24	14.6	140.37	3.19	1.28	"	"	" "
			Av.	13.9		Av.	1.00			
118	124	140	16	6.7	141.50	1.94	0.78	"	"	Uncomfortable. P.F.
103	116	143	29	11.8	130.37	2.75	1.10	"	"	
76	84	2:46	4	1.6	150.75	1.44	0.58	"	"	Very comfortable.
80	102	2:46	6	2.4	150.56	1.06	0.43	"	"	" "
72	88	75	0	0.0	139.87	2.96	1.18	"	"	Comfortable.
90	106	2:46	10	4.1	128.87	0.35	0.14	"	"	Comfortably cool.
			Av.	2.0		Av.	0.56			

AND VENTILATING ENGINEERS at the Bureau of Mines will soon be completed, so as to broaden the field of application of the results presented in this paper. With the completed information on hand any combination of temperature, humidity and air movement, within the practical limits, which is equivalent to the comfortable working values given above, can be readily determined by means of appropriate charts or tables.

Body Temperature and Pulse Rate

The rates of increase in rectal temperature and in pulse rate are plotted in Figs. 2 and 3 against dry-bulb temperature for still and moving air, respectively. The

TABLE 2. DATA AND RESULTS OF EXPERIMENTS

Test No. and Date 1928	Test Conditions	Subjects	Time Entered Chamber	Left Chamber	In Chamber hours	Rectal Temperature, °F. Initial	Average Time	Total Rise	Rate of Rise per hour	Initial Pulse
42D										
2-24	D.B. 80.0	Brubach	1:30	3:50	2.33	100.0	2.25	-0.5	-0.22	82
60-D	W.B. 52.0								Av. -0.79	
4-20	R.H. 60%	A.W. Dickert	1:05	1:35	2.50	99.0	2.42	-0.7	-0.29	100
		C.F. Moore	1:00	1:30	2.50	99.0	2.42	0.5	0.25	72
	D.B. 44.3	C.P. Yaglogiou	1:05	3:35		99.8	2.42	-1.0	-0.41	88
43D	W.B. 34.2	Brubach	1:00	3:30	2.50	100.4	2.42	-2.4	-0.99	88
	R.H. 30%									
2-26									Av. -0.70	
	D.B. 42.9	C.P. Yaglogiou	1:30	4:30		100.4	2.42	-1.8	-0.74	90
44D	W.B. 42.6	Brubach	1:45	4:15	2.50	100.4	2.42	-2.2	-0.91	78
	R.H. 100%									
3-2									Av. -0.83	
45D		W.S.Vineland	1:30	3:50		100.0	2.42	-0.4	-0.17	78
3-4	D.B. 86.3	W. Illig	1:15	3:45	2.50	99.2	2.42	1.0	0.41	84
	W.B. 63.4								Av. 0.07	
59D	R.H. 29%	A.W.Dickert	1:30	4:00	2.5	99.4	2.42	0.0	0.0	104
4-17		T.A.Donaghue	1:35	4:05		99.0	2.42	0.6	0.03	64
46D		W.S.Vineland	1:05	3:35		99.4	2.42	0.4	0.17	78
3-4	D.B. 85.5	W. Illig	1:00	3:30	2.50	99.4	2.42	1.0	0.41	80
	W.B. 65.5								Av. 0.28	
62-D	R.H. 100%	A.W.Dickert	1:05	3:35	2.50	99.0	2.42	1.2	0.49	100
4-24		T.A.Donaghue	1:00	3:30		100.2	2.42	0.1	0.04	78
47-D		W.S.Vineland	1:15	3:45		100.0	2.42	-0.4	-0.17	84
3-9	D.B.85.3	W. Illig	1:20	3:50	2.50	100.0	2.42	0.4	0.17	88
	W.B. 74.1								Av. 0.04	
58-D	R.H. 60%	A.W.Dickert	1:05	3:35	2.50	99.6	2.42	0.2	0.08	90
4-18		T.A.Donaghue	1:00	3:30		99.7	2.42	0.2	0.08	72
48-D	D.B. 82.0	C.P. Yaglogiou	1:05	3:35		99.5	2.42	0.9	0.00	84
3-11	W.B. 61.7	W. Illig	1:00	3:30	2.50	99.4	2.42	0.0	0.00	80
	R.H. 93%								Av. 0.00	
8-13		C.P. Yaglogiou	1:05	3:35		99.6	2.42	0.0	0.00	87
49-D	D.B. 71.2	J. Murray	1:00	3:30	2.50	99.6	2.42	0.8	0.33	96
	W.B. 66.3								Av. -0.03	
64-D	R.H. 27%	W.S.Vineland	1:00	3:30	2.50	98.8	2.42	-0.1	-0.04	68
4-29		T.A.Donaghue	1:05	3:35		100.2	2.42	-1.0	-0.41	70
50-D		C.P. Yaglogiou	1:05	3:35		99.7	2.42	-0.1	-0.04	82
3-16	D.B. 84.8	W. Illig	1:00	3:30	2.50	99.2	2.42	0.2	0.08	82
	W.B. 48.4								Av. -0.06	
84-D	R.H. 29%	W.S.Vineland	1:00	3:30	2.50	99.2	2.42	-0.6	-0.25	80
4-6		T. A. Donaghue	1:05	3:35		99.5	2.42	-0.1	-0.04	70
51-D		W.S.Vineland	10:30	1:00		100.0	2.42	-1.2	-0.49	68
3-20	D.B. 70.5	W. Illig	10:35	1:05	2.50	99.0	2.42	0.2	0.08	80
	W.B. 65.8								Av.-0.08	
55-D	R.H. 39%	C.P. Yaglogiou	1:05	3:35	2.50	99.7	2.42	0.2	0.08	80
4-8		T.A.Donaghue	1:00	3:30		99.0	2.42	0.0	0.00	72
52-D		J. Murray	1:05	3:35		99.4	2.42	0.2	0.08	80
3-27	D.B. 70.5	W. Illig	1:00	3:30	2.50	98.8	2.42	0.6	0.25	78
	W.B. 70.5								Av. 0.12	
87-D	R.H. 100%	W.S.Vineland	1:00	3:30	2.50	99.2	2.42	0.2	0.08	70
4-13		T.A. Donaghue	1:05	3:35		100.0	2.42	0.2	0.08	72
53-D		C.P. Yaglogiou	1:35	4:05		100.0	2.42	0.1	0.04	88
3-30	D.B. 93.2	W. Illig	1:30	4:04	2.50	99.4	2.42	0.6	0.25	82
	W.B. 78.0								Av. 0.09	
61-D	R.H.51%	W. S. Vineland	1:00	3:30	2.50	99.0	2.42	0.2	0.08	72
4-22		T.A. Donaghue	1:05	3:35		100.0	2.42	0.0	0.00	68
54-D		W.E. Miller	1:05	3:35	2.50	99.5	2.42	-0.5	-0.21	100
4-10	D.B. 71.4	T.A.Donaghue	1:00	3:30	2.50	100.0	2.42	-0.8	-0.33	78
	W.B. 61.2								Av	
63-D	R.H. 56%	W.S.Vineland	1:00	3:30	2.50	99.8	2.42	-1.2	-0.50	88
4-27		A.W.Dickert	1:05	3:35	2.50	98.8	2.42	0.0	0.00	102
									Av.-0.25	

percentages of relative humidity employed are indicated. In order to illustrate the physiological reactions at lower temperatures better, the results obtained from previous experiments at higher temperatures are also shown.

It will be recalled that the upper limit of the subjects' ability to compensate for atmospheric conditions, with still air, and at rest, lies around 90 deg. effective temperature. Fig. 2 indicates that when work is done at the rate of 90,000 foot-pounds per hour this limit is reached at a temperature of about 85 deg. fahr. Below this temperature the changes in rectal temperature and pulse rate are small because the body is capable of adjusting itself to the temperature of the environment. In this adjustment the physiological importance of the skin must not be

WITH AIR VELOCITY OF 350 FEET PER MINUTE

Final Before Full	After Full	Average Time	Increase	Body Weight in Pounds Initial	Loss	Rate of Increase	Rate of Loss. (lbs. per hr.)	Work Done Total No. of Pulls.	Total Foot-Pounds	Remarks of Workers at temperature condition.
88	96	2.29	10	125.13	0.87	4.4	0.37	1250	210000	Comfortable
						Av. 4.4	Av. 0.39			
92	116	2.46	4	113.06	1.00	1.6	0.40	1125	225000	Rather Cool.
78	102	2.46	18	138.32	1.00	7.3	0.40	"	"	Too Cool.
88	121	2.46	17	126.87	0.50	6.9	0.20	"	"	Too Cold.
84	119	2.46	14	128.70	0.50	5.7	0.20	"	"	Too Cold.
						Av. 6.3	Av. 0.20			
76	117	2.46	7	126.00	0.75	2.8	0.30	"	"	Too Cold
77	178	2.46	15	127.00	0.27	6.1	0.15	"	"	" "
						Av. 4.5	Av. 0.23			
108	151	2.46	52	150.13	2.27	21.1	0.95	"	"	Comfortable
108	133	2.46	37	141.25	2.37	15.0	0.95	"	"	Comfortably warm.
						Av.13.0	Av. 0.89			
120	128	2.46	23	113.69	2.13	9.4	0.85	"	"	" "
70	90	2.46	16	138.69	2.0	6.5	0.80	"	"	Comfortable
108	148	2.46	50	150.13	2.44	20.3	0.98	"	"	Comfortably warm.
116	149	2.46	53	141.50	3.0	21.5	0.12	"	"	" "
						Av.15.7	Av. 0.50			
120	124	2.46	27	113.87	2.0	11.0	1.20	"	"	Comfortable
84	116	2.46	24	129.13	2.13	9.8	0.88	"	"	Comfortably warm.
174	136	2.46	36	150.00	1.56	14.6	0.62	"	"	" "
170	126	2.46	30	138.50	4.00	12.2	0.16	"	"	———
						Av.13.6	Av. 0.72			
120	144	2.46	42	115.06	2.04	17.1	0.82	"	"	Comfortable
77	119	2.46	26	139.63	3.21	10.6	1.32	"	"	"
80	120	2.46	16	126.94	0.75	6.5	0.30	"	"	Very comfortable.
90	120	2.46	24	141.31	0.31	10.2	0.12	"	"	Rather cool.
						Av. 8.4	Av. 0.21			
90	120	2.46	21	126.37	1.13	8.5	0.35	"	"	Comfortable
118	148	2.46	37	129.06	1.56	15.0	0.62	"	"	Very comfortable.
						Av. 9.0	Av. 0.33			
64	98	2.46	3	151.56	0.81	1.2	0.32	"	"	Comfortable
68	72	2.46	1	139.50	1.08	0.4	0.43	"	"	Very comfortable.
84	118	2.46	19	127.00	1.00	7.7	0.40	"	"	" "
92	120	2.46	24	141.00	1.00	9.8	0.40	"	"	" "
						Av. 4.9	Av. 0.30			
78	84	2.46		151.62	0.80	0.4	0.30	"	"	" "
75	84	2.46	4	139.19	0.44	1.6	0.18	"	"	———
68	84	2.46	8	150.19	0.31	3.3	0.12	"	"	Too cool.
72	102	2.46	7	141.37	0.69	2.8	0.27	"	"	Very comfortable.
						Av. 2.2	Av. 0.23			
94	118	2.46	27	126.94	0.81	11.0	0.32	"	"	Comfortable.
70	92	2.46	9	140.0	0.56	3.7	0.22	"	"	"
97	126	2.46	32	129.13	0.37	13.0	0.55	"	"	"
96	128	2.46	34	130.75	—	13.8	—	"	"	———
						Av. 9.8	Av. 0.33			
77	94	2.46	16	151.34	0.37	6.5	0.15	"	"	———
78	94	2.46	14	139.0	0.75	5.7	0.30	"	"	Comfortable.
104	140	2.46	34	125.19	2.69	13.8	1.78	"	"	Too warm.
106	134	2.46	28	132.63	2.81	15.4	1.12	"	"	"
						Av.12.4	Av. 0.92			
90	118	2.46	27	151.75	1.37	11.0	0.56	"	"	"
84	97	2.46	23	-9.4	140.25	—		"	"	"
98	118	2.46	8	3.5	133.35	1.34	0.54	"	"	Very comfortable.
78	99	2.46	11	4.5	140.00	1.14	0.46	"	"	"
69	96	2.46	-5	-2.0	151.19	0.38	0.15	"	"	Comfortably cool.
92	118	2.46	4	1.6	113.50	0.38	0.15	"	"	———
				Av. 1.9			Av. 0.33			

overlooked. The regulatory functions of the skin are frequently inhibited not only by improper clothing, but by cutaneous infections and sluggishness of vaso-motor reflexes. It has been noticed that the latter type of individuals are more susceptible to heat and cold. The subjects of our experiments were mostly free from any skin affections and their clothing was light, so we are justified in assuming that their bodies functioned efficiently. The fact that air movement shifted the upper working limit of temperature from 85 to 90 deg. fahr. indicates that in still air the regulatory functions of the skin are carried on under greater difficulties because the air in immediate proximity to the skin remained warm and saturated. The remarks of the subjects also indicate that air movement within the comfort

zone renders working conditions more pleasant and cheerful. The absence of sensible perspiration in the presence of air motion may influence this decision.

Body Weight

The average rate of loss in body weight is shown in Fig. 4, and is similarly plotted against dry-bulb temperature with relative humidities of 30, 60 and 100

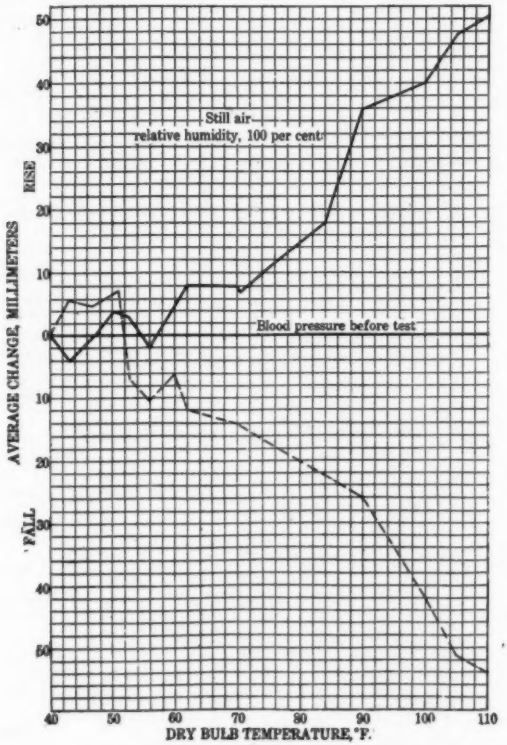

FIG. 5. VARIATIONS IN SYSTOLIC AND DIASTOLIC BLOOD PRESSURE IN STILL AIR, RELATIVE HUMIDITY 100 PER CENT

per cent. It will be noticed also that the loss increases at an accelerated rate above 85 deg. fahr. for still air and above 90 deg. for moving air. It must be remembered that this loss is by no means permanent, as it is due to the excessive perspiration of the subject. Although as much as 4 lbs. has been lost in one hour by subjects exposed to high temperatures, the weight is rapidly regained when water is drunk freely.

Below these temperatures the weight loss does not change much, but it is considerably higher for subjects at work than at rest. Body temperature or pulse-

rate seemed little influenced by drinking water, except that mouth temperatures were lowered temporarily.

The maximum variations in the systolic and diastolic blood pressure are shown in Figs. 5, 6 and 7 for still air experiments. The changes in these quantities at lower temperatures are very small, and the error involved in their measurements, and probably other causes are greater than their variations due to temperature conditions. The influence on blood pressure at higher temperatures is shown from previous experiments and the results are given in Figs. 5, 6 and 7. It is seen that the systolic pressure rises while the diastolic falls at high temperatures.

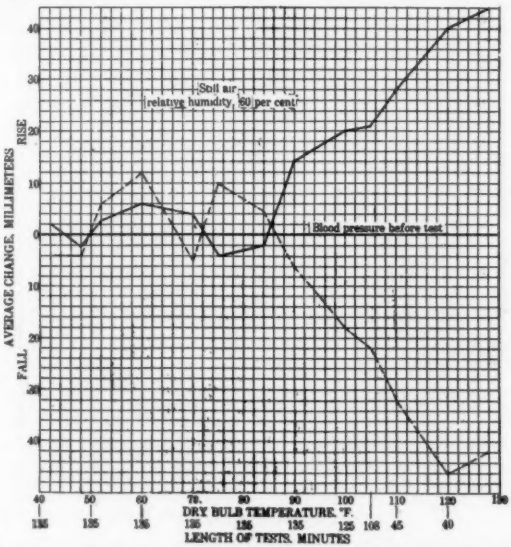

FIG. 6. VARIATIONS IN SYSTOLIC AND DIASTOLIC BLOOD PRESSURE IN STILL AIR, RELATIVE HUMIDITY 60 PER CENT

This change is noticeable at 100 deg. fahr. for 100 per cent, at 106 deg. fahr. for 60 per cent and at 120 deg. fahr. for 30 per cent relative humidities.

Conclusions

1. The results of these experiments definitely indicate to what extent atmospheric conditions influence human efficiency. The physiological responses to muscular work depend partly upon the severity of the exertion and partly upon the temperature, humidity and movement of the air. These three physical factors of the air must be within certain limits to allow the excess of body heat to be removed from the surface at an adequate rate depending upon the work output and the amount and nature of the clothing worn.

2. With the constant rate of work output of 90,000 foot-pounds per hour, 70 deg. fahr. dry bulb with ordinary humidities appears to be a good condition in which to work when light clothing is worn. The temperature could be varied from 60 deg. fahr. to about 78 deg. fahr. without appreciable discomfort. It is the writers' opinion that a fluctuating temperature, within certain limits, is more desirable than a constant optimum temperature.

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3. The importance of air movement has been emphasized in a previous report[4] in connection with the ability of men to perform work in comparatively high temperatures. At low temperatures that are within the limits of the compensatory regulation of the human body, the most important effect of air movement lies in its stimulating and cooling effect on the skin. The absence of sensible sweating, which is removed more rapidly in the presence of air movement, renders working conditions more cheerful.

4. After the elimination of the effects of temperature, the ability of a man to perform work within his particular comfort zone must necessarily depend upon

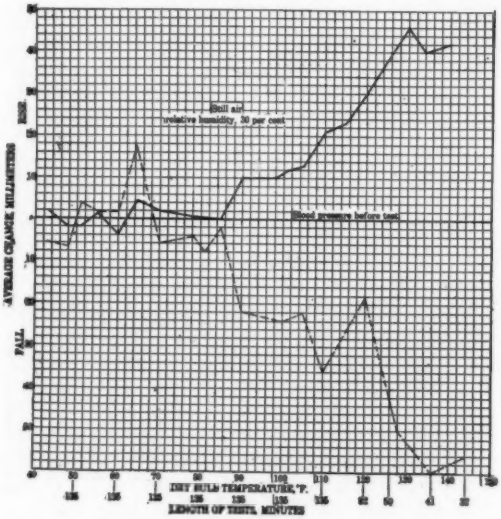

FIG. 7. VARIATION IN SYSTOLIC AND DIASTOLIC BLOOD PRESSURE IN STILL AIR, RELATIVE HUMIDITY 30 PER CENT

the fatigue of the active muscles. The working muscles exhaust their store of energy and the system becomes clogged up by the metabolic products. This accumulation prevents, according to Bainbridge,[5] the complete restoration of the fibrils to their resting condition after each contraction and the discharge of energy as each successive contraction diminishes.

5. Another important fact to be brought out in connection with the fatigue of muscles is the effect of training. With a given rate of work the physiological reactions of the subjects were found to be considerably less for the trained than for the untrained. For this reason each new subject was gradually trained to the routine of the work before his results were accepted as part of the data here given.

6. Acclimatization no doubt had its effect upon our experiments. However, within the comfort zone the changes in the physiological reactions are too small to be measurably affected by it.

[4] Work cited.
[5] The Physiology of Muscular Work, by Arthur F. Bainbridge, second edition, London, 1923, 226 pp.

No. 751

CLASS-ROOM HEATING AND VENTILATING WITHOUT DIRECT RADIATION

By J. R. McColl, Detroit, Mich.

MEMBER

MANY years ago, in a classroom in the Stevenson School, Flint, Michigan, during very cold weather, I found the temperature in the outside aisle of a classroom 13 deg. lower than in the inside aisle. This difference in temperature is the greatest I have ever found, and would probably be found only in a *blast system* in extreme weather. Four or five degrees difference, however, is not uncommon for this old type of heating and ventilating system.

But even with this fault in lack of uniformity in heating, it was the first successful system in the mechanical ventilation for schools, following, as it did, years of success in factory heating, where warmed air delivered by fans, was primarily designed to heat, but along with which came also ventilation. The failure of the then existing gravity or other systems in schools to give adequate ventilation, gave great impetus to forced ventilation.

The blast system, employing warmed air for both heating and ventilating, although successful when properly designed, installed, and operated, had the serious drawback suggested above, of lack of uniformity in heating. The cool zones along the outside wall were a natural result of the downward currents of cold air, which were cooled below average room temperature by their contact with the outside wall, particularly with the glass. This partial failure of the blast system naturally led to the so-called *split system*, wherein direct radiation is installed along the outside wall. This radiation is usually of such capacity that it will take care of the total heat loss from the room, as well as break up the downward currents of cool air above referred to. Air for ventilation in this system is introduced approximately at room temperature. Although this system simplified the double plenum chamber to a single tempered air chamber, and did away with some of the complications of the blast system, it introduced, at a much increased expense, the direct radiation system, making in reality a dual system for the school.

The split system, with its direct radiation for heating, makes it possible to warm classrooms without ventilation. In all probability, the great majority of mechanical ventilating systems for schools, as they exist today, are of this type,

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and unless they are in charge of conscientious engineers or under the control of thorough-going supervising engineers, the great tendency is to cut down on the use of the fan system and to operate the heating system only. Unfortunately, we are not as conscious of poor ventilation as we are of poor heating, and consequently the lazy or careless operating engineer can get by undetected, with poor ventila-

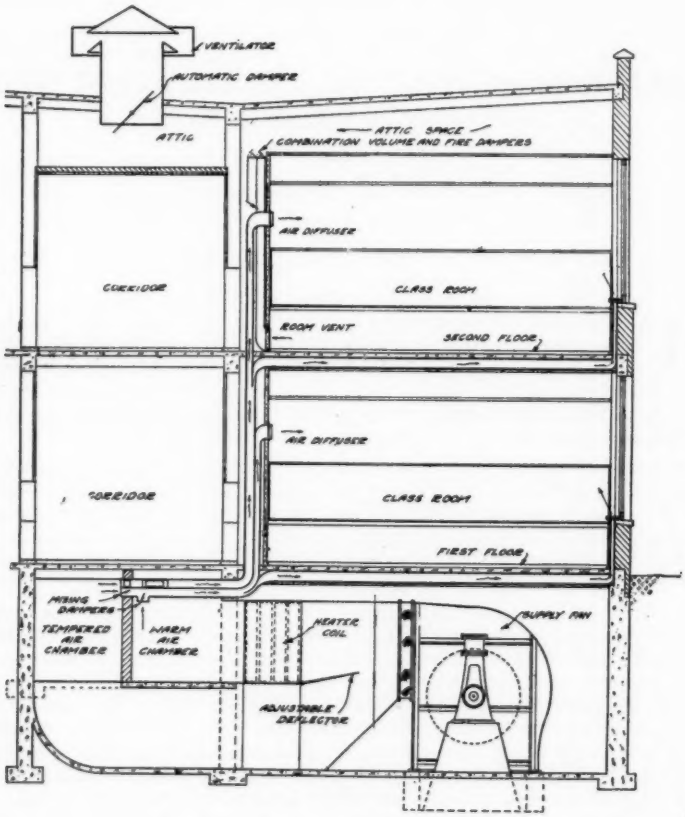

FIG. 1. TYPICAL SECTION SHOWING FAN, HEATER, PLENUM CHAMBER AND DISTRIBUTING SYSTEM

tion if he has the split system. My observations lead me to believe that with this type of system, not more than half are giving real sanitary results, sometimes due to faulty design or installation, but almost always to poor maintenance and operation.

When we see the overheated and poorly ventilated classrooms and filthy conditions existing from basement to attic in such a large percentage of the split

systems, it is not surprising that there has grown up such a strong sentiment for the open window and the getting away from the more complicated mechanical systems. I contend that operating engineers and their superiors are more to blame than any other one group for the sentiment which has grown up against mechanical ventilation for schools, and they are to be condemned as much for overheating as for poor ventilation.

This digression may be somewhat off the subject, but it has its direct bearing on a study to simplify the mechanical ventilating system and, at the same time, to overcome the inherent drawbacks of the original blast system, for, after all, the blast system is about as simple as can be conceived for real and positive ventilation, to say nothing of the heating.

It was with this in view that a blast system was worked out which is in use in

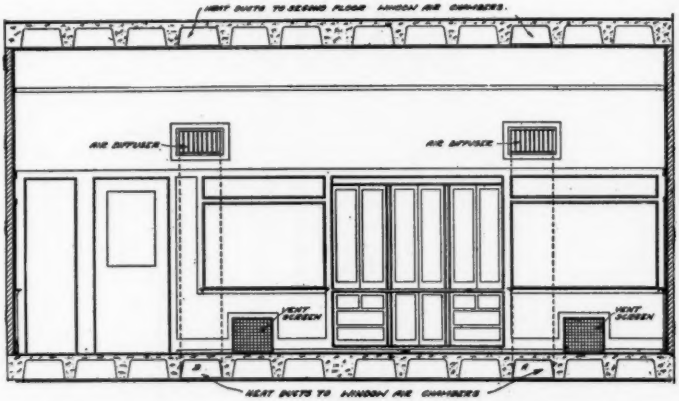

FIG. 2. ELEVATION OF THE INSIDE WALL OF A TYPICAL CLASSROOM

the Detroit schools and those of many other cities in the middle west. The purpose of this paper is to describe this system. In principle, it differs from the old type of blast system, in that a certain amount of the air is introduced through a slit in the window sill. This slit is about the thickness of a match and extends the full length of the window. This air is supplied from a shallow chamber below the window, as will be described hereafter in connection with the drawings, and its purpose is to break up the cool down currents of air already mentioned, the actual process being, according to smoke and thermometer tests, to mix with the downward currents, warming them and rolling with them across the classroom, approximately at breathing level, to the vents on the corridor side of the classroom. It took considerable testing to get the right volume and velocity for this air delivered through the window sills. The best results were obtained with approximately 20 per cent of the air for the room delivered through the window slits and 80 per cent from the two diffusers on the corridor wall.

The tendency in recent years to build schools, without basement rooms, has aided the design of the blast system, where two chambers, one carrying tempered air and the other warm or hot air, are necessary to supply the properly tempered air to each room through mixing dampers and individual ducts. A basement corri-

dor with an insulated dividing wall serves admirably for these two plenum chambers, making short connections, all that are necessary for the risers to the various rooms. The fan equipment, drawing its supply from down a shaft which extends through the roof and is also connected with the attic, makes it possible to recirculate any proportion of the air, all rooms being vented to the attic. The air cleans-

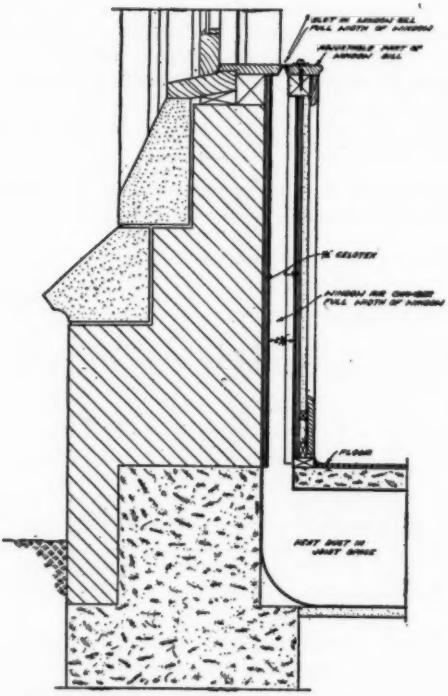

FIG. 3. SECTION AND PERSPECTIVE OF OUTSIDE WALL OF CLASSROOM

ing and humidifying equipment and the automatic temperature control equipment make it possible to deliver to each plenum chamber, cleansed, humidified air of the right temperature. Two supply ducts lead to each classroom, and the room thermostat operating the mixing dampers automatically controls the temperature in the room.

Fig. 1 gives a typical section showing the heating and ventilating system, which is the subject of this paper. In a way, it is a typical double plenum chamber system, with the warm air chamber and tempered air chamber side by side, separated by a hollow tile insulated wall. These two chambers form the basement corridor, making it possible to connect with the risers to the various rooms, without long sheet metal ducts found in the old blast systems. The pan type of con-

struction for the floors makes it easy to convey a portion of the air for each room over to the window for distribution through the window sill, as herebefore described. Reference to Figs. 2 and 3 will show how two of the spaces between joists in the pan of construction for each room are utilized for this purpose. They are marked *A* and *B*.

It is evident, also, from these cuts, that each room has two separate supply

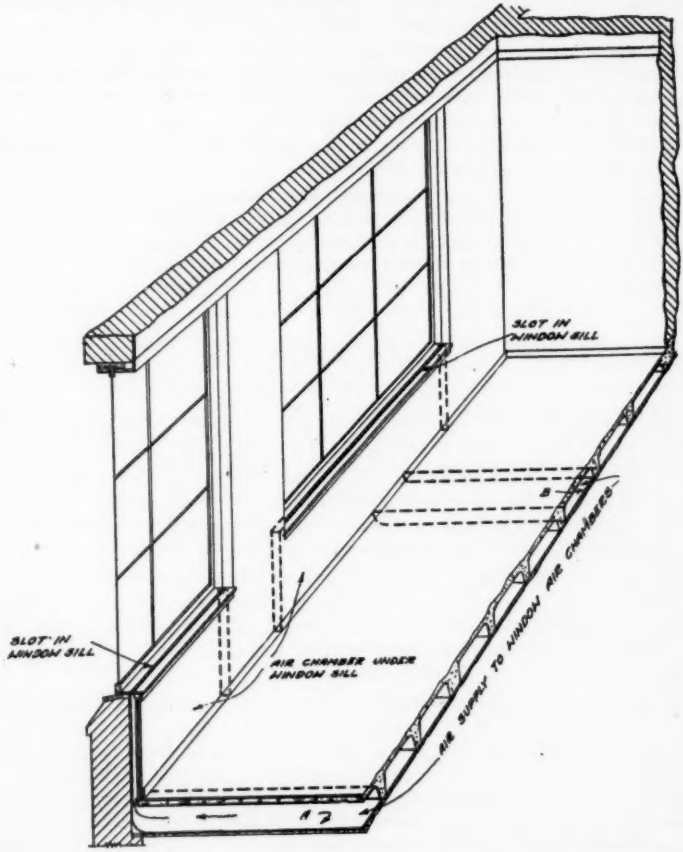

FIG. 4. SECTION THROUGH WINDOW AIR CHAMBER

ducts and two separate vents, which makes it possible to divide the regular classroom into two small rooms or to enlarge any standard classroom without requiring any changes in the heating and ventilating system.

Figs. 3 and 4 show the shallow window boxes or plenum chambers with their supply ducts and the slots in the window sills through which the warm air is discharged to break up the downward cool currents, already discussed. These win-

dow chambers are built in as a part of the building construction and to one who walks into the classroom, the outside wall is a plain, bare wall. The slit in the window sill would give one an impression that the carpenter did a poor job of joinery, but when one puts his hand over this slit and feels the warm air coming out, its purpose is readily realized. This slit is adjustable so as to control the velocity of the air at various points. The volume of the air is controlled by the deflecting damper shown in Fig. 1. The total amount of air for the classroom is controlled by a volume damper, not shown on the drawing.

The window air box or plenum chamber (see Figs. 3 and 4), is only $2^3/_4$ in. in depth and is insulated on the inside as well as the outer side. The row of pupils along the outside wall of the classroom do not suffer from the cold drafts of the old blast system nor the radiant heat from radiators in the split system. They are sitting in a room where the temperature is practically uniform and where there is no obstruction to the outside aisle.

The author is indebted to Malcomson & Higginbotham, Architects, Detroit, for cooperation in working out the distributing system and to J. H. Walker, of the Detroit Edison Company and David King, Supervising Engineer of the Detroit Board of Education. for assistance in determining proper volumes and velocities.

DISCUSSION

E. C. EVANS: I would like to ask you, Mr. McColl, why you do not use the overhead discharge in the classroom from the pan duct. That was at one time your system, and you apparently have discarded it in this system.

J. R. MCCOLL: The overhead system involves more expense. We found, in our smoke tests, the overhead distribution was unnecessary, as the wall diffusers, in conjunction with the window supply, gave excellent distribution.

JOHN HOWATT (WRITTEN): Heating of classrooms without direct radiation is a common practice in larger cities of the middle states where the all-blast system of combined heating and ventilation had its origin, the development in recent years having been in improved methods of carrying the air to the rooms and improvements in its distribution in the rooms themselves.

The success of the all-blast system of heating and ventilation is dependent upon the successful operation of a heat regulation system that is accurate and sensitive and which will maintain the mixing dampers in intermediate position without flopping. In order to avoid excessive quantities of air being delivered into the rooms with the mixing dampers thrown to the tempered air position, it is necessary to provide adjustable dampers or closing off devices to artificially build up resistance through the tempered air side of the system to equal the greater resistance through the warm air side due to the additional resistance offered by the heating stacks. This feature is frequently omitted in designs of ventilating systems of this type and the omission is one of the causes of complaints of drafts.

My experience has shown that the most frequent complaint received against a ventilating system is complaint of drafts and if we are to design systems that are considered satisfactory, drafts must be avoided, particularly drafts that strike the occupants of a room on the back.

In all of the discussions concerning the present methods of heating and venti-

lating school buildings, the critics of mechanical ventilating systems lay great stress upon the fact that many millions of dollars are invested in mechanical ventilating plants throughout the United States which are never used. They cite example after example where expensive mechanical ventilating systems have been provided in buildings by owners but which for reasons of economy or other reasons are never operated.

This condition is never found where the heating and ventilation of the classrooms are combined as they are in the all-blast system. It is the system generally used in the Chicago schools and we have experienced very little opposition to the mechanical ventilation of our buildings largely attributable, in my opinion, to the fact that it is absolutely necessary for the engineer in charge of the plant to operate his blower system whenever the outside temperature is below 60° in order to make the classrooms comfortably warm. It is a well-known fact that the temperature of the room is noticed by the teachers quicker than is any other air condition. With the air-blast method of combined heating and ventilation if the room is warm, it is also receiving ventilation.

The cost of school building construction is receiving critical attention throughout the entire country and every way in which it can be reduced is being considered. The all-blast system of combined heating and ventilation is the lowest first cost system of mechanical heating and ventilation that has been devised.

There is no question but that there is some difference in temperature in different parts of any room when outside weather conditions are severe. This is particularly true on the windward side of a building when the wind velocity is in excess of fifteen miles per hour and of course the difference in temperature is aggravated by poor building construction or loose window sash and window frames. However, I have never discovered more than 5 deg. difference in temperature under the most severe conditions between the first row of seats on window side of the room as compared to the row next the inside wall. That may be because we, realizing the enormous losses through window cracks, try to keep our window frames calked and window sash weatherstripped. A chilling action of the window exists, however, under any circumstances and the conditions in the room are improved by providing a supply of heat under them. In the split system this heat is supplied by direct radiation. In the all-blast system it may be supplied as proposed by Professor McColl through slots in the window sills or as has been done by Mr. Lewis, in other cases by specially designed baseboards with openings in their upper faces. As I see it the big problem in ventilation not satisfactorily solved is distribution and that is improved by introducing some air under the windows on the outside wall as proposed. We have experimented with this addition to the conventional arrangement for introducing air and have several buildings in operation with air inlet registers in the wall just below the windows and find that room temperatures are more uniform than without them, but in severe weather it does not entirely overcome the difficulty. Double windows which can be opened have been found more effective.

I take this opportunity to stress what I believe is a most important factor in the success or failure of any mechanical ventilating system, and that is proper care, maintenance and operation of that system after it has been installed. Two plants of a similar design may give entirely different results, one satisfactory and the other unsatisfactory, dependent upon the operator in charge of each. The attention given to the sanitation and cleaning of the heating devices and air passages, air shafts, washers, etc., have a great deal more to do with the results obtained than most engineers realize. Dust settles on horizontal surfaces only. Very little

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if any, will settle on vertical galvanized ducts. A great deal will settle in any horizontal duct. You would not think of filtering and purifying water making it fit for human consumption and then deliver it into dirty and unsanitary water mains neither should we think of cleaning and purifying the air making it fit for human use and then discharge it into filthy unsanitary ducts. In our mechanical ventilating design we should eliminate, as far as possible, all inaccessible horizontal air delivery passages, as they are bound, sooner or later, to become filthy and foul smelling. For this reason we have adopted for our Chicago school building designs the sub-corridor or tunnel system with vertical sheet metal riser ducts to the classrooms; these sub-corridor tunnels being 14 ft. wide and 7 in. high and with smooth cement finish, hosed out every night are easily maintained sanitary. We do not design a ventilating system that cannot be cleaned out easily and do not place the equipment in inaccessible places where it is difficult for the operating engineer to get at in order to take care of it. If care and operation are not made convenient the equipment will be neglected and the heating and ventilating system will not give satisfactory results.

Operating rules that prohibit teachers from opening classroom windows should be avoided as it is a human trait to oppose any compulsory measure. It is not necessary to have such a rule provided the blowers used are selected to give excess pressure in the plenum chamber so opening windows in one classroom will not interfere materially with the air supply to any other room. It is surprising how seldom windows are opened in a building that is ventilated by a good mechanical system where the teachers know they may open them if they desire.

A. L. SANFORD (WRITTEN): It has been our experience here in Minneapolis, with the extreme winter weather, often averaging 30 deg. below zero for a week at a time, that the split system is the best type of heating which can be installed in our schools. We find that it is much easier as well as cheaper, to keep the entire building above 50 deg. at night, rather than allow the temperature to drop. With a hot-blast system in which all of the B.t.u. loss is taken care of by the temperature of the air, we find that the room cools off immediately after the fans are shut down, and it takes a long time in the morning to get them up to temperature again.

It is very easy with the blast system, to heat the air content of the room and building, but it is not so easy to bring up the temperature of the walls and furniture to a comfortable point. It is on that account that we are using the split system, and we try to maintain a temperature above 50 deg. at night even in the cold weather.

The blast system, wherein a part of the air is delivered in front of the windows, is one which has been tried previously and I should not care to comment on this without having the drawings before me. This idea is one, however, which should work out very satisfactory provided the operation is correct and the outdoor temperature does not reach an extreme.

In the next-to-the-last paragraph of the paper, Mr. McColl states that in his system of ventilation, "the row of pupils along the outside wall of the classroom did not suffer* * *from the radiant heat from radiators in the split system."

In the Minneapolis public schools we install a radiator shield which is located $2^1/_2$ in. from the radiator. Also, the radiator is installed with a clear space of $2^1/_2$ in. from the radiator to the wall. This gives in effect, an enclosing box of the most efficient type around the radiator, insuring a maximum efficiency of the radiator, and also prevents any radiant heat from affecting the pupils next to the outside

wall. So that this criticism of Mr. McColl's does not apply to a split system properly installed with radiator shields.

N. W. DOWNES (WRITTEN): The strong point brought out in Mr. McColl's paper in favor of the hot-blast system is the fact that the hot-blast system insures ventilation while the flexible split system does not when operated under lax supervision.

Like Mr. McColl, the writer is of the opinion that the sentiment in favor of uncontrolled ventilation has grown up largely through failure to properly operate split systems, due not only to carelessness on the part of the operating engineer but in large part to faulty design and installation, making satisfactory results impossible.

Our experience in Kansas City would indicate that properly designed, installed and operated split systems operate more economically than hot-blast systems just as carefully designed, installed, and operated. At the close of school in the afternoon the house fans are shut down and the radiation used only. In fact the house fans are operated only at such times as school is in session, the radiation taking care of building at all other times, in the sense that it does not permit building to completely cool down. Room temperatures drop as low in severe weather as 50 deg. Our records show that our split systems are operating at a cost per cubic contents of 20 per cent less than our hot-blast systems.

The hot blast design as described by Mr. McColl is a marked improvement over the conventional hot blast design used in the past and no doubt will meet the deficiencies of the old design admirably, in taking care of the cold down drafts on the outside wall, which was the chief factor as pointed out by Mr. McColl, for introducing the split system.

The automatic temperature control of rooms served by a hot blast system is not so simple and constant as in the split system, in that the temperature of the hot air is manually varied to suit outside temperature conditions and often the temperature of the hot air is carried too high. In view of this, it would seem to the writer that conditions might obtain in a system such as Mr. McColl describes, that with a too high diffusing temperature on a fairly cold day, the thermostat would cause mixing damper to change from hot to tempered air causing tempered air to flow in at window sill which would be too low in temperature to give the results desired, namely, break up the cold down drafts.

The writer has designed and installed both the conventional hot blast and split systems and has under his supervision the operation of both. Aside from economy, the split system with wall type radiation on the outside wall seems to maintain a more uniform temperature and makes for better comfort than the hot-blast system.

The first cost of any installation is, of course, of prime importance and no doubt such a system as Mr. McColl describes can be installed in a school without basement rooms and with trunk ducts and lateral ducts to window sills provided in the general contract at as low a cost and possibly cheaper than a split system. This, however, would not be the case where individual ducts had to be carried back to fans in schools equipped with basements.

It has been the writer's experience that ventilating ducts designed as a part of the building construction regardless of exacting detailed drawings, miscarry. Especially is this true of small ducts. Rough surfaces, projections, offsets and square turns result unless the heating engineer is on the job to supervise the form work, and it is obviously impossible for the engineer to do this.

XUM

Many perversities are committed in the name of ventilation in the rather thinly populated areas where the architect is not only an architect but qualifies as a structural, electrical, and mechanical engineer as well, and the result of such perversities is the sentiment now gaining favor for window ventilation.

It would be a happy day for all if a system such as Mr. McColl has so admirably designed could receive the publicity and be received with the same interest as the propaganda turned loose on window ventilation.

The heating and ventilating engineer in most part serves the public who are too busy with their own affairs to properly appraise his service. The average layman concedes every art and science involved in the assembly of a complex structure to the architect who accepts the concession and disposes of the engineering as he sees fit and to his best advantage. A wise architect wisely selects his engineer, realizing that success or failure of his building depends on the engineering.

At such times as the public will insist on qualified engineers, such as Mr. McColl, a satisfied public will result and uncontrolled window ventilation methods will be relegated to the museums.

H. P. DEMPSEY (WRITTEN): This paper of Mr. McColl's is very interesting as it gives us a solution for the blast system. There are certain questions that come to mind such as:

1. The cost of installation of this type of blast system as compared with the split system.

2. How are the corridors, wardrobes and toilet rooms ventilated, that is, is air supplied to corridors and vented through wardrobes and toilets? Are wardrobes located in classrooms or corridors and how ventilated?

3. What is the usual temperature of hot air and of tempered air leaving fans in zero weather?

The blast system, of course, compels the engineer to run the fans for heating as well as ventilation. It is true the split system has allowed the operating engineers to let the ventilating fans lay idle but this may be overcome to a certain extent by placing only sufficient direct radiation under the windows to care for the heat loss up to approximately 40 deg. in zero weather.

As Mr. McColl has pointed out strong sentiment for open window ventilation has grown due to lack of or faulty operation of fans in split system, but I believe that we are responsible as a Society for this condition. It has been known for some time that this condition exists and as a body we should have given concerted action to remove or modify the cause and I still believe there is time for such action.

No. 752

DEVELOPMENT OF THE ART OF HEATING AND VENTILATING IN CANADA

By L. M. ARKLEY,[1] KINGSTON, ONT.

MEMBER

THE subject of heating and ventilating divides naturally into two sections, first the heating and ventilation of comparatively small dwelling houses and the same applied to large public buildings, factories, and shops. They will be treated in this order.

The method of heating small dwellings probably progressed in the following order:

a Heating by open fires, without ventilating flues;
b Heating by open fires with ventilating flues;
c Heating by open fire place with chimney attached;
d Heating by box stoves;
e Heating by box stoves bricked in to form a kind of hot-air furnace;
f Heating by the standard type of hot-air furnace;
g Heating by hot-water systems;
h Heating by low pressure steam.

One of the first references to this subject may be found in the *Proceedings of the Royal Society of Canada* (1905) where it is stated that, in 1627, Champlain built chimneys in his "abitation" or combined dwelling house and fort, for ventilation purposes. These chimneys were not connected to the fire places, but served to remove some of the smoke and soot from the rooms as indicated in Fig. 1, which shows a general view of one of Canada's first buildings.

About this time it is recorded that Louis Herbert and Guillaume Couillard, two of the earliest settlers in Quebec city, built smoke escapes in their homes similar to those of Champlain. They also fitted sashes in the window frames and hung doors, and arranged them all to open and close.

In 1670, is found the following description of a typical dwelling which has some bearing on the heating question: "The four walls were made of logs that would hew to about one foot square, these were fastened securely at the corners, and the seams calked with moss and plastered with clay." This construction should

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give a coefficient of heat transfer of less than 0.1 B.t.u. per sq. ft. per degree difference of temperature, which is better than some of the fancy modern wall construction that exists today. The kitchen had a special fire place for cooking and "two or three chimneys heated the main part of the house." Double windows and doors were also used about this time. The white population of the whole of

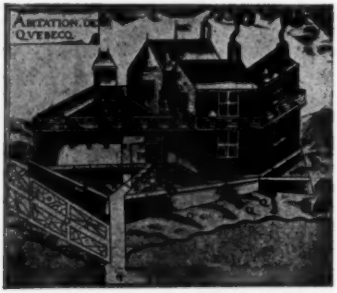

FIG. 1. CHAMPLAIN'S ABITATION, QUEBEC

Canada was less than 10,000, so that the field for heating engineers was rather limited, and as near as the writer can gather there was no controversy on between the advocates of window ventilation and those who favored the mechanical system.

It must be remembered that wood was the fuel used at this time and it is recorded that the inhabitants did not realize the advantage of having it dried before using, and the result was much sickness, due to the fumes and smoke in the unventilated houses. Wood was first sold publicly for fuel in 1647 at Montreal and brought 1 shilling and 3 pence per cord. It held the field as fuel in Canada until about 1875 when the old Grand Trunk Railroad began to use coal.

FIG. 2. CHATEAU DE RAMESAY, MONTREAL

The next development, the large open fire place built of stone with chimney attached, came in about 1675 and was the standard method of heating and ventilating for years. One of the best examples of these old fire places can be seen today in the Chateau de Ramesay of Montreal, which was built in 1705. In the vaults of this old building with its walls of solid masonry four feet thick are

two fire places, 5 ft. wide by 4 ft. high by 3½ ft. deep, in practically as good repair as when they were used over 200 years ago. In the side of one fire place is a large oven which was used for cooking purposes. The building is now heated by means of steam coils, which according to the best available information were put in about the year 1885.

The following is a short résumé of the development of the *stove* which came into use after the open fire place. While this applies particularly to the United States, it is almost impossible to separate the development of heating and ventilating between these two countries.

In 1409, the first stove was made in Alsace, and it was nearly 250 years later that Christopher Sower of Germantown, Pa., made what he called a jamb stove. The jamb stove consisted of a cast iron box built into one side of the kitchen fire place, one end opening into an adjoining room, the other being heated by the fire. This was perhaps the first attempt to heat other rooms beside the one in which the fire place was located.

In 1744, Benjamin Franklin invented a stove which was manufactured and

FIG. 3. NEW PARLIAMENT BUILDING, OTTAWA

sold in Philadelphia about that time. It, like the Sower stove, was connected to the open fire place, but jutted out into the room so that the heat was given off by three sides, instead of one.

In 1752–60, six plate or box stoves were made by Baron Stiegel, and were put together at Providence, R. I., and Troy, N. Y. These were the forerunners of the modern stove. In 1820, the Conant stove was made in Brandon, Vt., and in 1836, a stove having an illuminated case of cast iron and mica, enclosed tubes, a check flue, and a direct draft damper, was made by James Atwater, of New York, and almost at the same time the Stanley square heating stove was brought out.

The first base burner was patented in 1853 by Jordan R. Mott, Sr., of New York. This was a self feeder, feeding the coal from a magazine to a fire pot, something on the order of the modern furnaces of that type.

From these beginnings the modern stove was evolved, and there is still room for improvement on it.

That there were many defects in the stoves in use at this time is clear from an article on ventilation written by an engineer by the name of C. Dowden of Newark, N. J. In this article, which appeared in *Appleton's Magazine*, in 1852, he worked out from the CO_2 theory that the quantity of air that should be supplied per

person per hour for ventilation should be not less than 480 cu. ft. or about one quarter of that supplied today. He next called attention to the necessity of two openings, one for exhaust and another for supply of pure air, if ventilation was to be secured. He argued at some length in favor of ventilation of bed rooms at night and stated that the sickness and suffering experienced more particularly at night were due, not so much to the night air, as to excess of CO_2, absence of sunlight, rapid reduction of temperature, and the air being saturated with moisture.

He follows this with the statement that most of the stoves in use at that time had so many crevices that it was impossible to keep them from leaking gas into

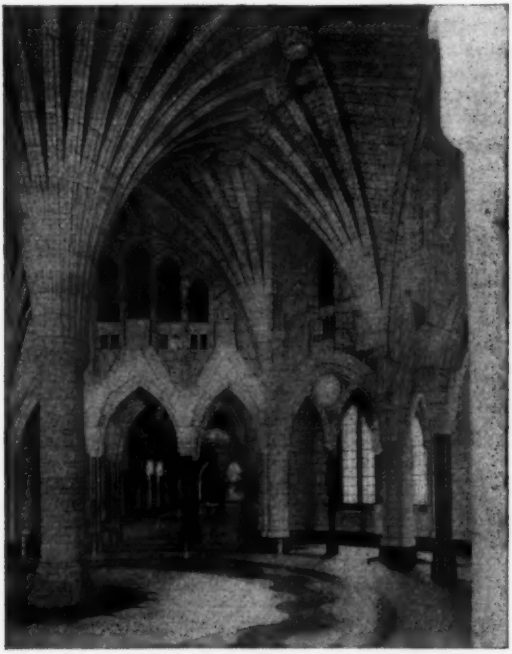

FIG. 4. MAIN ENTRANCE HALL LOOKING TOWARDS NORTH CORRIDOR, PARLIAMENT BUILDING, OTTAWA

the room, that in many cases the flues were too small and often choked with soot, and that the pernicious habit of placing dampers in the smoke pipes was followed. He concluded by describing what he called a ventilating stove which would do away with most of the difficulties experienced as follows: First the stove manufacturers were to make a gas tight stove,

"Then a tube, 4 to 8 in. in diameter, must be inserted under the floor commencing in the open air and running to a spot immediately below the stove and opening into the room; then make an air-chamber under the stove plate to receive the external air, and let sides extend up around the stove to keep the air for a short distance in contact with the hot cylinder. Having thus secured the means of obtaining a supply of fresh warm air, it will be an easy matter to carry out the second part of ventilation, *viz.*,

removing the vitiated air; this can be effectually done by simply making the opening in the chimney about 2 in. larger than the smoke pipe, and placing a register around the pipe to regulate the amount of air passing out."

The connection between the preceding and heating and ventilation in Canada is indicated by the fact that H. Ruttan of Coburg, Ontario, saw Mr. Boyden's article in *Appleton's Magazine* and was so impressed with the similarity of the ideas expressed with his own, that he immediately wrote commending the article and subscribed for the magazine. This engineer, H. Ruttan, was one of the first Canadian heating and ventilating engineers and the same man who later took the old Cockle stove of England, remodeled it into a furnace and introduced it into the States, as mentioned by Dr. E. V. Hill, in his discussion of Prof. Winslow's paper.

From this time on the development of heating in the cities may be considered

FIG. 5. COMMONS CHAMBER FROM SPEAKER'S GALLERY

representative. One of the oldest cities in Canada is Kingston, Ontario, which was founded by Count Frontenac in 1673. The following is a résumé of the development in Kingston.

As early as 1858, some of the Kingston bank buildings were heated by hot-air furnaces, made by encasing an ordinary box stove with brick and extending the fire box to take a 4 ft. stick of wood. The first steam heating system was put in a dwelling house about 1855. It was known as the Gould System of steam heating, and consisted of a sheet iron pot or tank for a boiler fitted with drop tubes about 18 in. long, which hung over the fire. These tubes were very close together and tapped into the bottom sheet. This furnace was bricked with a long fire box suitable for wood. The radiators were made of sheet iron also, two pressed sheets being used fastened together at all four edges and held apart about $1^1/_2$ in. by stay bolts spaced on 6 in. centers. A heating system similar to the one above was installed in the Kingston Custom House about 1856. The first record of hot-water heating was in 1865, when one of the bank buildings was heated by this system. Box coils were used and these were encased with cast iron screens with a marble slab on top for esthetic purposes. There

were several other buildings heated in this way about this time, one of them being the Court House.

Of the larger buildings, one of the most interesting heating systems is that installed in Rockwood Asylum. It was put in in 1866, and is still being used. It might be described as the steam coil and vault system. Long vaults were built in the basement and in these were placed 28,000 ft. of 1 in. wrought iron steam pipe, using return bends and headers. The coils are connected to flow and return pipes and the returns drain back to the boilers placed at a lower level. The hot air from the vaults is supplied to the rooms above by tin-lined boxes or flues, built in the walls. Air from outside the building is brought to the vaults through similar boxes. This

FIG. 6. POWER HOUSE, PARLIAMENT BUILDING, OTTAWA

system is very similar to that described later on in heating the Old Parliament Buildings in Ottawa, and may have been put in by the same heating engineer, C. Garth of Montreal.

Among the first buildings to be heated by other means than by stoves, was an old stone building at the Royal Military College, used for training midshipmen for boats on the lakes, and now used as a dormitory for the Cadets. In each end of this building was placed a cast iron furnace made similar to a big box stove, but mounted on wheels on a track. These furnaces were bricked in and space left around the sides and top for heated air which was conveyed in ducts to the halls in the floors above. The object of the wheels and track was to provide a means of cleaning and repairing the furnaces. These were put in about 1869.

The first example of heating and ventilating of the larger buildings was that of the Old Arts building of Queen's University, in 1875. The halls and some of the

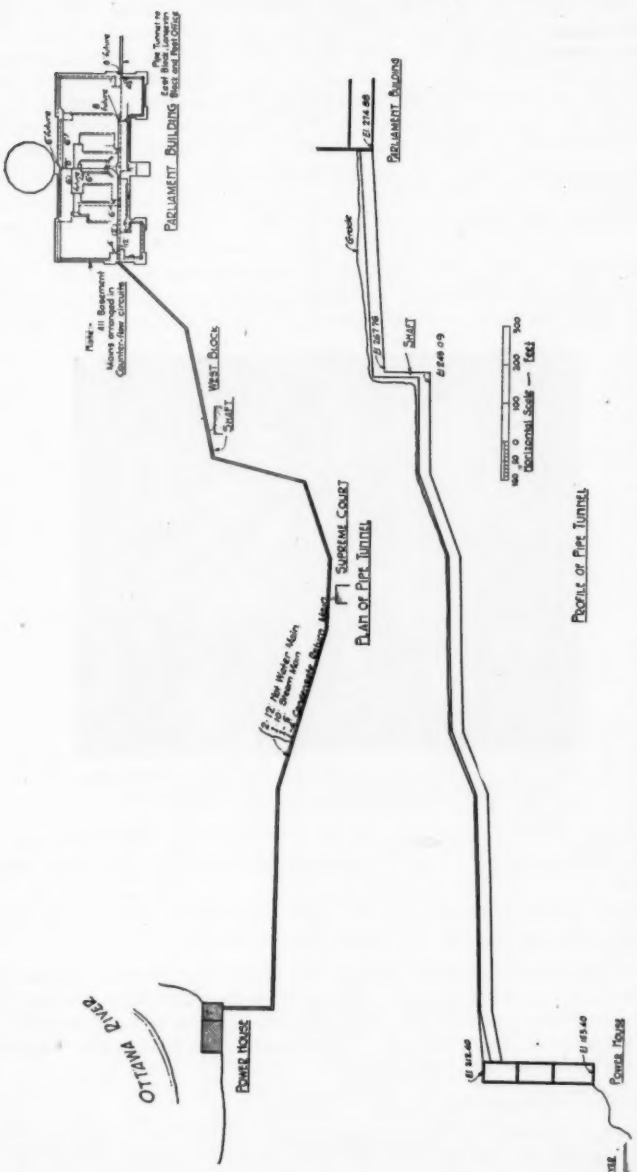

FIG. 7. PROFILE AND PLAN OF PIPE TUNNELS, PARLIAMENT BUILDING

rooms were heated by direct radiation. Radiators were made with a cast iron base, with short pieces of pipe screwed into the top of the base and capped. Steam coils were placed in tin-lined boxes in the basement and air from outside passed over the coils and then up through tin-lined ducts to the rooms above; it was the janitor's duty to regulate the incoming air to this box. It operated on the two-pipe system, the boiler being placed in a pit in the basement. This building is now connected to Queen's Central Heating Plant to be described later on in this paper.

Cast iron furnaces made by Warden-King and Co., of Montreal, first made their appearance about 1876, and the public schools were equipped with heating systems about 1880, while 10 years later fans for ventilating purposes came into use.

In Montreal, one of the first gravity hot-water heating systems was furnished for Madam Masson's residence at Terrebonne in 1856, and this was equipped with a Garth hot-water boiler, a new departure in hot-water boilers at that time.

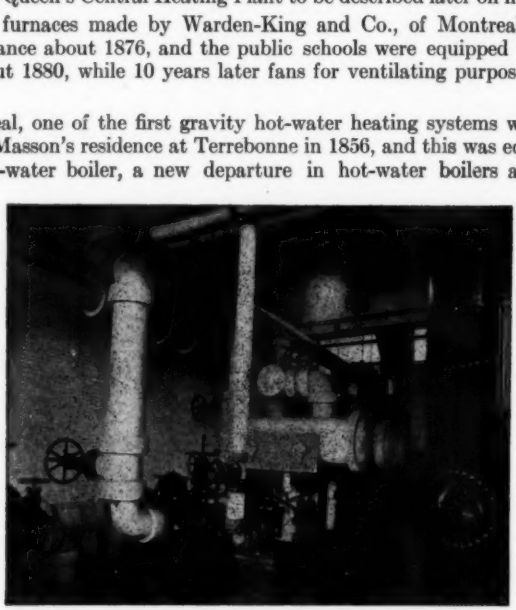

FIG. 7A. INTERIOR VIEW OF POWER HOUSE SHOWING WATER HEATERS AND CIRCULATING EQUIPMENT

One of the first vacuum systems used was put in the Greenshields Block in 1896 and Oscar Paré installed a forced hot-water system in Longue Point Asylum about 1900.

One of the early furnaces used in the neighborhood of Montreal for the heating of vineries and conservatories was described as follows:

"It was made with a fire-brick circular base and ash pit on which was mounted a stout boiler plate cylinder four ft. in diameter by 6 ft. high. This was lined with fire brick, one thickness on end, flat side to the fire, four tiers high and inside this was one continuous coil of pipe of about 50 ft. in length. This furnace was taken out in 1870 after having been in use for 50 years."

Old Parliament Buildings, Ottawa

Perhaps no better contrast between heating and ventilation of early and modern large buildings can be cited than that of the Parliament Buildings at Ottawa.

In 1859, notices were issued inviting tenders for heating and ventilating the

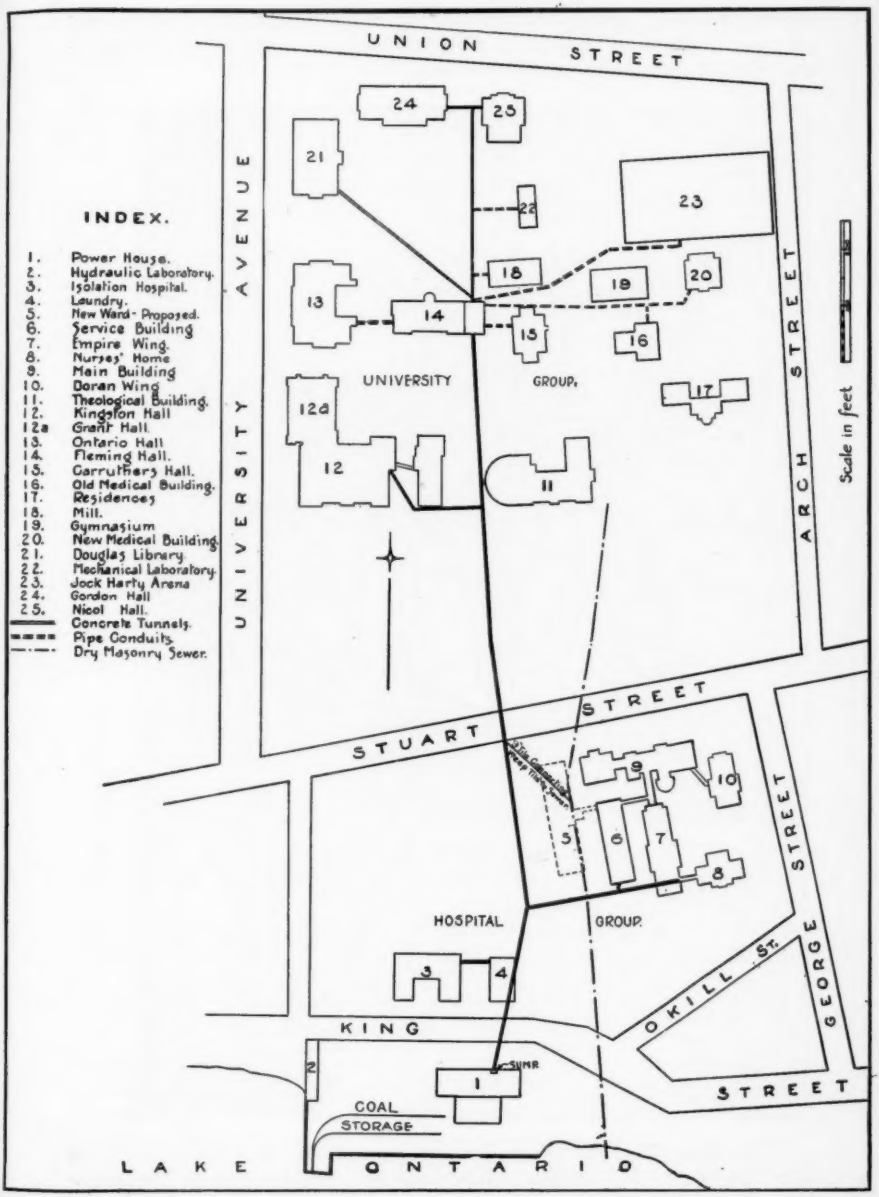

FIG. 8. PLAN OF GROUNDS OF QUEEN'S UNIVERSITY AND KINGSTON HOSPITAL, KINGSTON, ONTARIO

main Parliament Building and two large Departmental Buildings. The successful man was C. Garth of Montreal and the following description of the system he employed is taken from the report of a Commission printed in 1863.

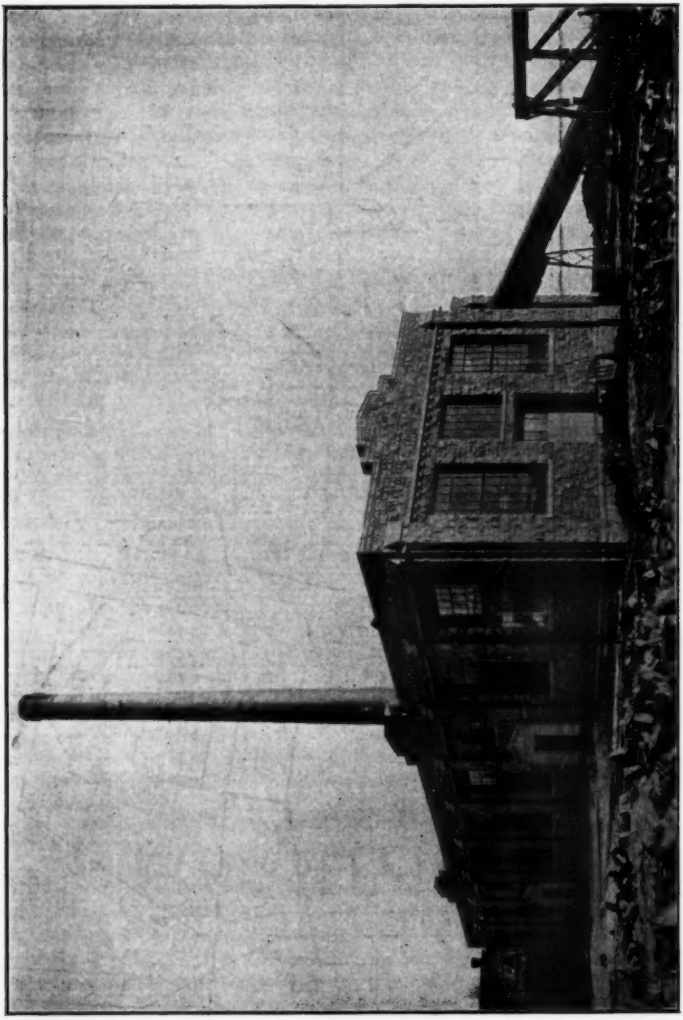

FIG. 9. POWER HOUSE, STEAM LABORATORY AND CHIMNEY, QUEEN'S UNIVERSITY

"The mode of heating embraced by Mr. Garth's contract is a combination of the steam coil and vault system, in this system vaults or chambers are built underneath the building in which coils of iron pipe are placed, in this way all the air used is heated and then conveyed through flues in the walls to the rooms. The boiler room is

outside the building to be heated and placed 10 ft. lower than the steam coils, in order to save heat and to make it possible to get the returns back to the boilers by gravity. Ventilation is provided as follows: external air is supplied to the heating vaults through long underground ducts, in this way it is tempered and does not cause trouble from excessive condensation in the pipes first coming in contact with the air. Circulation of the air is secured by placing two 24-in. iron smoke pipes from the boilers inside a ventilating shaft 15 ft. square by 128 ft. high. The heat from the smoke pipes rarefies the air in the shaft and causes sufficient suction to remove the vitiated air from the Legislative chambers and the library to which the ventilating shaft is attached. The

FIG. 10. INTERIOR VIEW OF BOILER ROOM SHOWING MAIN BOILER UNITS WITH STOKERS AND OVERHEAD COAL BUNKER, QUEEN'S UNIVERSITY

heated air is introduced overhead and the vitiated air drawn off near the floor which is known as the 'downward method of ventilation.' "

Before completing his plans for this installation Mr. Garth made a tour of inspection of the cities of New York, Philadelphia, and Washington and investigated all the heating and ventilating systems installed in those cities, at that time, his remarks throw some light on the state of the art in the United States at this period. He says:

"I inspected with great care the systems in use in the public buildings in Washington where the fan is used instead of external ducts. The objection to the fan is the draughts it causes. On its first introduction into the Legislature chambers in the Capitol, the air was brought in under the risers of the steps and the draughts were annoying to the members. Next, a register was placed near every member's seat and at his own control, but this was objected to for the same reason. Lastly, it was introduced by hopper openings in the walls, but this did not satisfy those in the galleries. I also learned that there was no proper provision made for removing the

vitiated air and that with the fan system they had trouble, in cold weather, from the water freezing in the coils."

Mr. Garth also mentioned that the new wing of the Montreal gaol was heated by his system, but that the air was carried through a duct only 24 ft. long and that in this building they had difficulty keeping the water in the coils from freezing in very cold weather. For the above reasons, Mr. Garth recommended the use of external ducts to introduce the air rather than fans.

New Parliament Buildings, Ottawa

In 1916, the main Parliament Building at Ottawa was burned, and in September of that year the corner stone of the new building was laid. Fig. 3 shows the new building with main tower partially completed, this tower is now complete and adds greatly to its appearance. Fig. 4 shows an interior view, that of the main

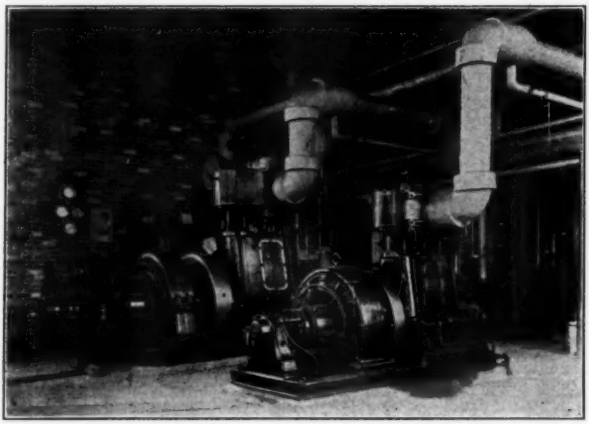

FIG. 11. TWO MAIN GENERATING UNITS IN POWER HOUSE WITH FEED WATER HEATER AND PUMPS IN BACKGROUND

entrance hall and, Fig. 5 shows the Commons Chamber from the Speaker's Gallery. These views were taken from the journal, *Construction*, and serve to show some of the problems involved in heating the building. The following description of the heating and ventilating system is from M. F. Thomas, who was responsible for its design and construction.

The question of heating the building with electric current was first gone into thoroughly, but it was found that this method would be too expensive and use too much power, and it was finally decided to heat by means of coal and to remove the power plant some distance from the main building in order to reduce the fire hazard. The site chosen shown in Fig. 6 is west of the Parliament grounds, in a cove in the river bank. At this point, the river forms a small bay and space was finally provided by cutting down a portion of the rock cliff and setting the structure into the bank. The cliff here is 65 ft. in height above the high water level and the power house building is designed so that the roof slab is at the street level; this provides a convenient method of delivering coal to the overhead bunkers in the boiler room.

The boiler room contains four 500 hp. boilers equipped with automatic stokers, operated on natural draft from a radial brick chimney, 9 ft. inside diameter by 180 ft. high. It also contains all modern equipment such as feed water heaters, coal weighers, soot blowers, feed and circulating pumps, etc.

The whole building except the Commons and Senate Chambers and several corridors is heated by direct radiation. There are 886 radiators aggregating 44,341 sq. ft. of heating surface operated as a forced circulation hot-water system. For warming the rooms in the tower where the elevation is too great for the hot-water system, about 2000 sq. ft. of steam radiation is installed. To assist in the control of the temperature of different sections of the building under varying wind conditions, groups of rooms having the same exposure are served by one branch main fitted with a diaphragm valve under the control of a thermostat located in a typical room.

Ventilation and in some cases heat to balance the losses is provided by a positive

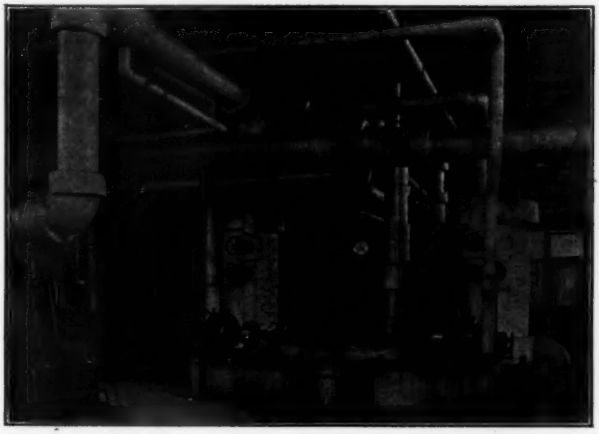

FIG. 12. GENERATORS AND CENTRIFUGAL PUMPS FOR CIRCULATING HOT WATER TO THE HOSPITAL

circulation of warm air to the Commons and Senate Chambers and to large corridors where the architectural details did not permit, or where it was undesirable to use, direct radiation. The two chambers each have complete systems separate from other parts of the building.

The ventilating systems consist of 7 fresh air supply fans with a total capacity of 176,000 cu. ft. per min., 17 air washers, 10 steam operated air tempering and re-heating units having a total surface of 6475 sq. ft. operated in the forced circulated hot-water system, and 10 exhaust fans having a total capacity of 148,000 cu. ft. of air per min. All the air supplied to the building by the ventilating systems enters from the interior courts, is tempered to 50 deg. fahr. by steam coils and washed by water sprays. The exhaust fans remove air from the two chambers, the large committee rooms, the kitchen, and from all locker rooms and lavatories.

A concrete tunnel 6 ft. 6 in. wide by 7 ft. 6 in. high connects the power house with the main building and in this are placed the two 12-in. hot water mains, one 10-in. and one 5-in. steam main which furnish all heat required.

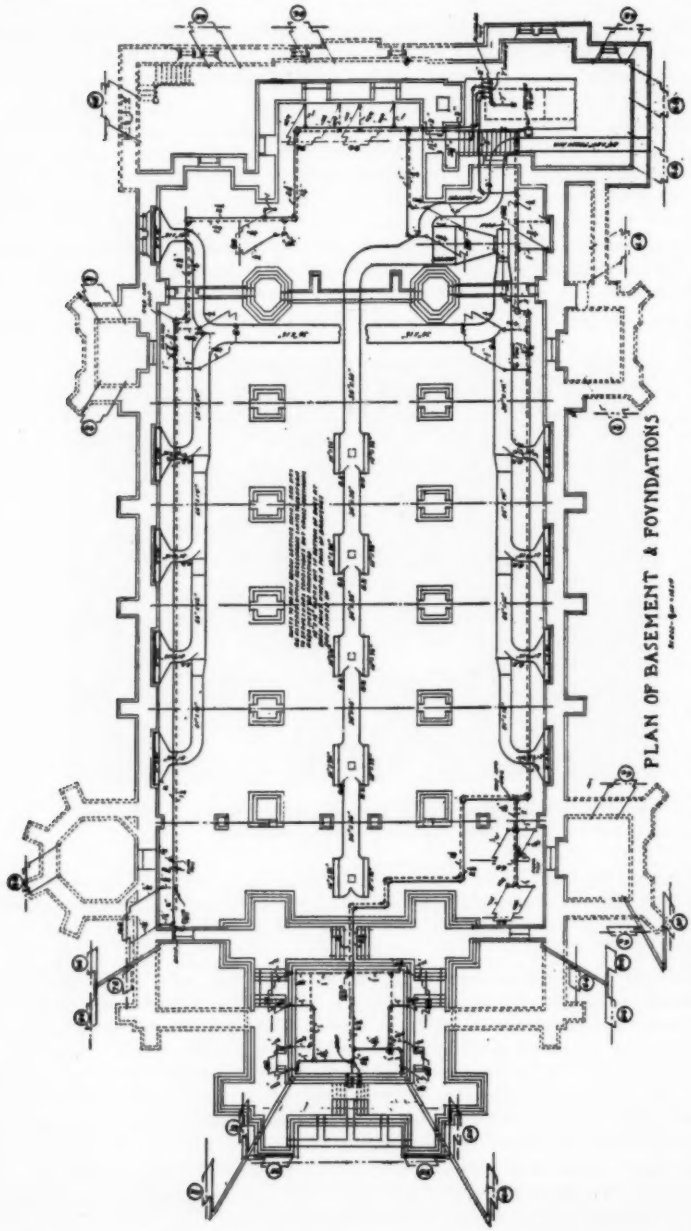

FIG. 13. PLAN OF BASEMENT AND FOUNDATIONS, CHURCH OF THE HOLY ROSARY

Fig. 7 shows profile and plan of tunnels and relative positions of power plant and buildings heated.

Queen's University Heating Plant

As an indication of the development of central heating in Canada the following description of the heating system at Queen's University, Kingston, Ontario is given.

As shown in Fig. 8 the central heating plant which serves the University and Kingston Hospital buildings is situated on the shore of Lake Ontario and is marked No. 1 on the map.

The building is a combined power plant and thermodynamics laboratory and is built of Kingston limestone to conform in appearance to the buildings which it heats. It is a one story building, the part facing King St., having a frontage of 144 ft. by 40 ft. wide while the boiler room at the back is 48 ft. × 80 ft. Fig. 9 shows the power plant and stack with a glimpse of Lake Ontario beyond. Coal can be unloaded at the plant from lake boats drawing not more than 10 ft. of water and, of course, an unlimited supply of water can be taken from the lake at small expense.

The capacity of the plant is 1500 hp. of water tube boilers. The boilers are equipped with automatic chain grate stokers, soot blowers, superheaters, coal weighers, and feed water meters, and the draft is supplied by a reinforced concrete chimney 7 ft. in diameter at the top by 150 ft. high. The coal is elevated from the coal storage area by an inclined endless belt and discharged into an overhead bunker of 100 tons capacity from which it is fed by gravity through the coal weigher to the stokers. The coal is moved by hand only once from the time it is discharged to the storage pile until it is disposed of as ash. An interior view of the boiler plant is shown in Fig. 10. The engine room contains one high speed Bellis and Morcom engine direct connected to a 150 kw. d. c. generator, a second unit the same as above, but of one-half the capacity and one Robb Armstrong direct connected unit of 150 kw. capacity. (See Fig. 11.) These machines are used for supplying the University buildings with light and power, and for operating the motor driven refrigerating machines serving the rink.

Hot Water Heats Hospital Group

The hospital group is heated by hot water generated by exhaust steam heaters in the engine room, Fig. 12, and circulated to the hospital and back, a distance of 500 ft., by small turbine driven centrifugal pumps. The temperature of this water is under thermostatic control and very easily regulated. Any exhaust steam not required for the hospital, or for heating boiler feed, goes to the University buildings which are heated by low pressure steam. All the new buildings are heated by the vacuum system while the older ones operate on the gravity return system. The returns are all pumped back to the central plant and are used over again as boiler feed. There are two distinct types of heating load, first the building which require heat only while the class and laboratory work is going on, and buildings such as the library, rink, gymnasium, etc., which require heat until late at night. It has been found that by connecting these on separate steam lines quite a saving can be effected by shutting the steam off completely when not required and supplying just enough to keep the temperature well above freezing.

The central plant is connected to Fleming Hall by a concrete tunnel 1300 ft. long, with a cross section of 4 ft. by 5 ft. 9 in. All steam and return pipes as well as electric cables are brought through this tunnel, and distribution of steam and electricity is made from this point.

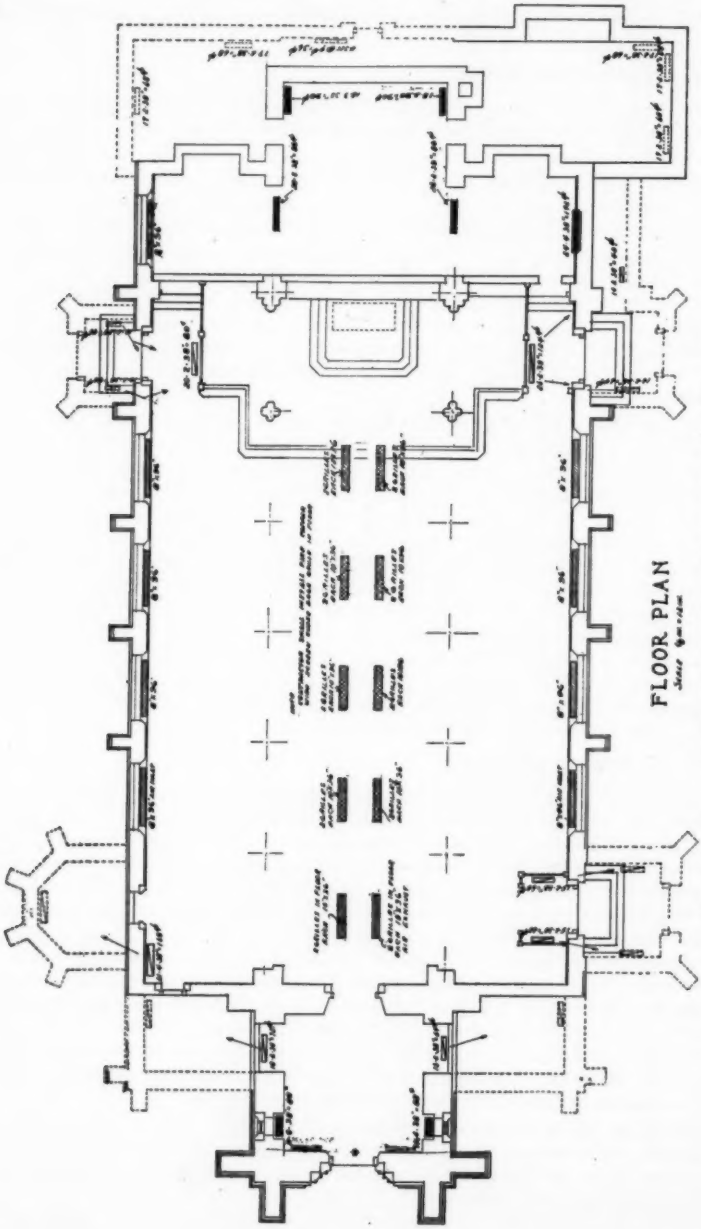

FIG. 14. FLOOR PLAN, CHURCH OF THE HOLY ROSARY, TORONTO

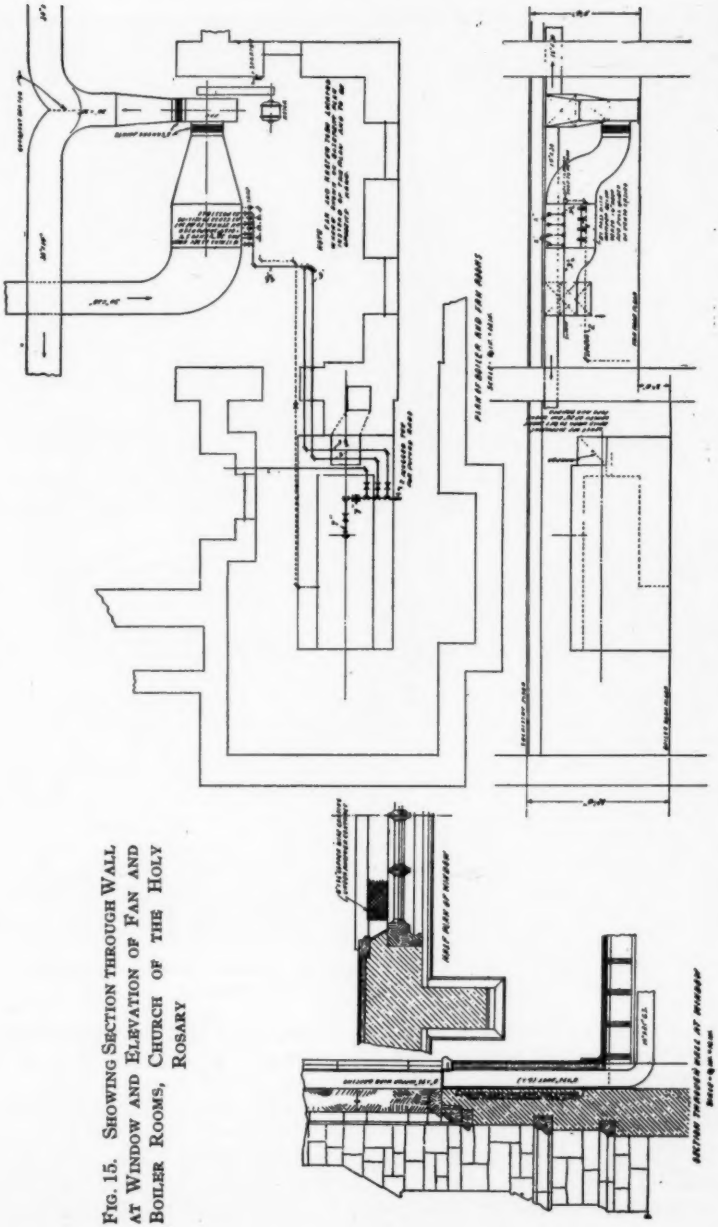

FIG. 15. SHOWING SECTION THROUGH WALL AT WINDOW AND ELEVATION OF FAN AND BOILER ROOMS, CHURCH OF THE HOLY ROSARY

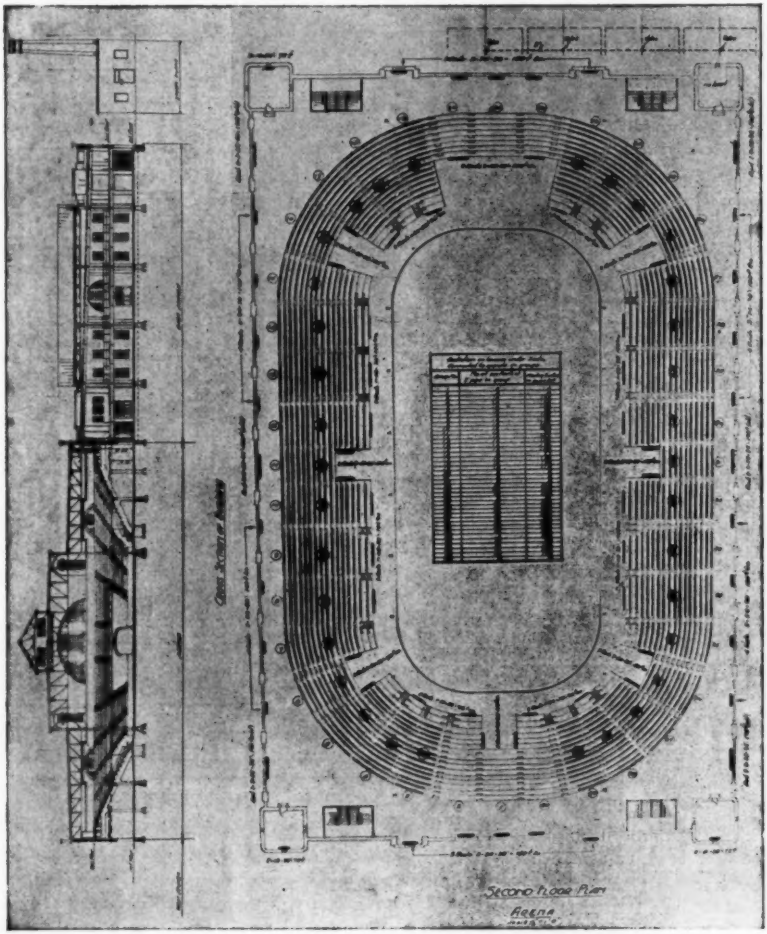

FIG. 17. CROSS SECTION FIG. 16. PLAN OF HEATING SYSTEM, COLISEUM, TORONTO

There are about 37,000 sq. ft. of direct and 6500 sq. ft. of indirect steam radiation in the University buildings, and 3700 sq. ft. of steam and 25,500 sq. ft. of hot water radiation in the hospital group.

Church of the Holy Rosary, Toronto

An interesting example of a combination of forced hot-air heating with direct radiation is shown in Figs. 13 and 14. For church heating it has the advantage of doing away with radiators in the body of the church and it makes a neat layout

architecturally. As shown on the plans, Fig. 15, the heated air comes up through hollow walls to the window sills, about 7 ft. above the floor where it is discharged, and the recirculated air is taken back to the fan through grilles in the floor of the center aisle. Provision is made for bringing in a certain amount of fresh air and there is a hand operated by-pass damper around the vent coil.

A very uniform distribution of heat may be secured by properly reducing the size of the ducts as they recede from the fan, and by dampering the outlets if necessary.

The designer of this layout, H. H. Angus, states that a similar installation has been operating in a Toronto church for several years with great satisfaction to the congregation.

Toronto's Largest Building

One of the largest buildings in Toronto is the Coliseum located on the grounds of the Canadian National Exhibition. This building is 600 ft. long, 393 ft. wide, and has an amphitheater 378 ft. long, 235 ft. wide, 52 ft. high, and has a cubic capacity of 3,000,000 cu. ft. The building is used during the two weeks of the Exhibition and the amphitheater is used during the winter for athletic contests, flower shows, live stock exhibits, etc. It therefore has to be heated up at short notice after being cold for long periods of time.

Direct Radiation Used

The designer of the heating system, M. F. Thomas, states that in deciding the proper method to use, consideration was given to a fan blast system, but later this was abandoned in favor of direct radiation. The heating surface was arranged in three general groups, the first consisting of single column radiators on the wall rising from the walk-way to the side terraces, second by 2-in. pipes located under the seats, and the third in the form of ordinary radiators placed round the wall on the floor, at the level of the upper terraces. The intention of the first group is to furnish some direct heat for the occupants of this part of the building and to create a circulation which would draw the cold air away from the oval. As this oval is enclosed by a tight board wall it was found that the building could be warmed up very much quicker by opening the gates to let the pool of cold air inside the oval flow out to replace the air heated by the radiators on the lower levels.

The second group of heating surface in the form of sections of 2 in. pipe, bent to conform to the steps of the terraces, consists of 34 sections, each containing from 8 to 16 pipes. Each pipe in a given section has a $^3/_4$-in. connection on each end to sloping supply and return branches located under the terraces. This group of pipes operates as one radiator being controlled by one valve and one trap.

Steam is furnished by four 72 in. H.R.T. boilers which operate at 100 lb. The steam is reduced to a pressure of from 1 to 2 lb. in the building. Oil is used as fuel and there has been no trouble heating the building in about half a day.

The Temperature Problem

It was found that best operating conditions could be obtained by securing a temperature of about 60 deg. fahr. at the time the audience began to assemble, then cutting off all direct radiation, except that on the windward side. With a crowd of 7000 or 8000 in the building, only a small part of the radiation need be used during the evening, even though the temperature was but 10 deg. above freezing with a strong wind blowing. Figs. 14 and 15 show details of this interesting heating system.

Acknowledgments

The data given in this paper has been obtained from many sources. Much of that referring to Kingston came from the firm of McKelvey and Birch, which has been in the heating business since 1854, and from old employees of this firm.

In addition to the above, the author wishes to acknowledge data from the following engineers: Melvern F. Thomas, Harry H. Angus, and H. R. Flett of Toronto; J. Druce, C. Drever, and N. Van Pattent of Kingston; and J. P. Linton of the Garth Co., Montreal. He is also indebted to the following firms: The Gurney Foundry Co., The Taylor-Forbes Co., Toronto, and the Garth Co., of Montreal.

It is surprising how little written data can be found on a subject of this kind and perhaps the main justification for writing this paper is that as the years go by the men, who carried on in the pioneer days, pass out without leaving any particular record and much valuable information is lost. The subject cannot, of course, be treated completely in a paper of this length, but if the author has been able to fix authoritatively a few of the milestones in the art of heating and ventilating in Canada, the object of the paper has been achieved.

No. 753

OBSERVING WARM AIR IN CIRCULATION

By Thornton Lewis, Philadelphia, Pa.*

MEMBER

WHEN the heating of a building is mentioned, what is really meant is the heating of the air in that building. This statement will seem rudimentary to heating engineers, but the writer wants to lay emphasis upon it, for although this has been a self-evident truth and has been mentally agreed to, it has been ignored to a large extent in the design and application of heating equipment.

As a matter of every day fact, many engineers have fallen into the habit of treating a building to be heated to a given temperature as a container into which could be poured a given quantity of heat, or in which this given quantity could be generated and that no matter how or where the heat was introduced, it would fill the container equally. Perhaps this could be illustrated by a gallon bowl, which,

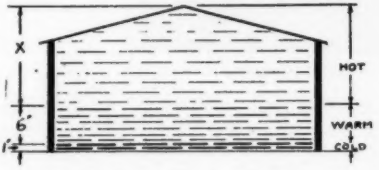

Fig. 1. Normal Stratification of Air

Fig. 2. Circulation of Heated Air with Direct Radiation

if filled with a gallon of water at a given temperature, could be said to be heated to that temperature equally throughout. Too frequently then the fact is lost sight of that no matter what quantity of heat is put into a building, it will not heat the building to an even temperature throughout. This refers to the different temperatures that will exist at the floor, in the working zone and the upper areas.

At this point, then, a definition of what is meant by heating a building is in order.

To heat a building to a given temperature is to maintain that given temperature with small variation, throughout the working zone, which zone is generally agreed to be the space immediately over the entire floor area to a height of approximately 7 feet.

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* President of York Heating & Ventilating Corp. Phila., Pa.

Paper presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, Lexington, Ky., May, 1926.

To say that a building is properly heated where the average of the temperatures maintained is the temperature desired, is not always true, and in most cases will

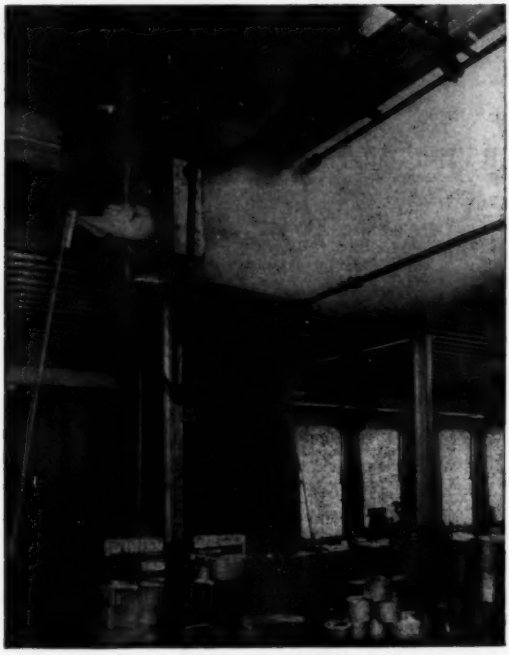

Fig. 4. Disc Fan Unit Heater in Action

prove absolutely false. If it is desired to maintain 60 deg. fahr. in a room, and the temperature near the floor is 30 deg. and near the ceiling 110 deg., the average would be 70 deg., or 10 deg. in excess of that desired, but the room would not necessarily be properly heated, but would, without doubt, be most uncomfortable.

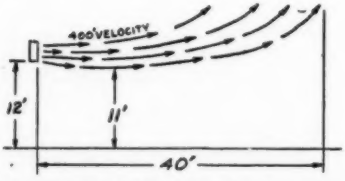

Fig. 3. Circulation with Disc Fan Unit Heater

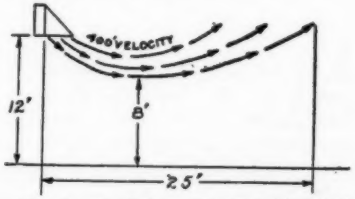

Fig. 5. Circulation with Disc Fan Unit Heater with 45 Degree Deflector Outlet

A condition approaching this rather extreme case is prevalent in practically all industrial plants.

If the question of comfort of the occupants is ignored, there remains the economic fact that this condition is wasteful of fuel. Equivalent results as to com-

fort may be secured at considerably less operating expense. It, therefore, seems that it is necessary for the heating engineer to study this subject diligently, in

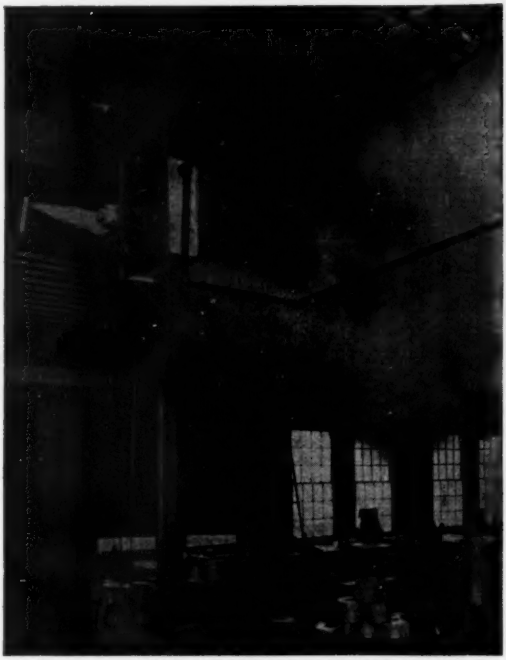

Fig. 6. Start of Test of Disc Fan Unit Heater with 45 Degree Deflector Outlet

order that in the design of heating appliances, for the future, this overheating of the upper part of buildings will be avoided and provision made to move the heat into the working zone where it is desired.

It is to call attention to this situation and present some of the observations of the writer and his fellow workers in the field of industrial plant heating, that this paper is presented for consideration.

In Fig. 1 an attempt has been made to indicate by a diagram the stratification of air as to temperature or density, that exists in any building, due to natural causes. Natural forces maintain this relative effect no matter what kind of a heating system is installed. It is the duty of engineers to so arrange the heating equipment that the temperature difference between floor and ceiling will be brought to that minimum which is consistent with initial and operating costs. To do so, the natural forces that tend to make this difference a maximum must be partly overcome.

Dr. C. W. Brabbée, in his excellent paper, The Heating Effect of Radiators (November, 1925, JOURNAL A.S.H.&V.E. discussed by this Society last January), calls attention to this subject and shows by his tests that from 10 to 20 per cent or more of the fuel can be saved by properly designing and placing radiators. At the same meeting R. V. Frost, after nearly 12 years of research, confirms and goes

Fig. 8. Smoke Tests of Unit Heater with Downward Discharge

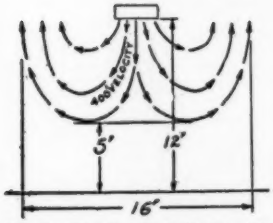

Fig. 7. Disc Fan Unit Heater with Downward Discharge

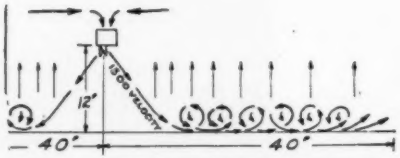

Fig. 9. Circulation with Suspended Heater with Housed Centrifugal Fan

Fig. 10. Suspended Heater with Housed Centrifugal Fan in Action

Fig. 11. Photograph Taken after Smoke Has Diffused through Building

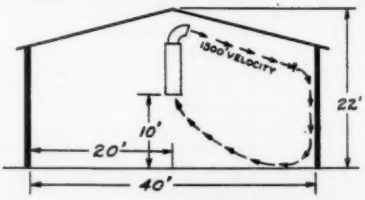

Fig. 12. Expected Circulation with Centrifugal Fan Suspended Unit

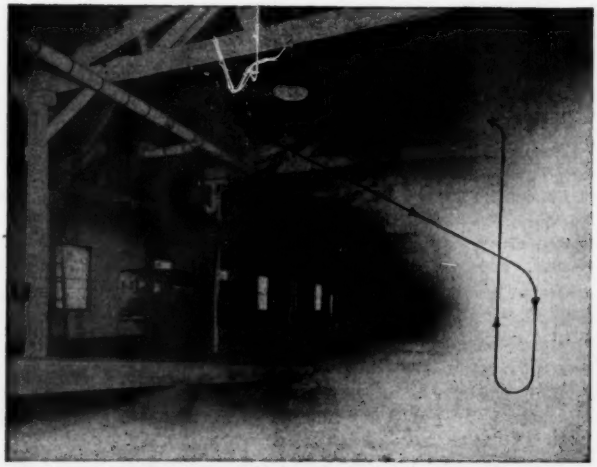

Fig. 13. Actual Circulation of Air from Suspended Centrifugal Fan Heater

even beyond Dr. Brabbée's conclusions, and says a saving of from 20 to 30 per cent of the fuel may be made by proper design. Both of these engineers refer to the direct radiation system. The investigations and tests of the writer indicate that, by the use of unit heaters properly designed and located, it is possible to save 15 to 30 per cent of the fuel required when compared with direct radiation, blower systems, or unit heaters as frequently improperly employed.

The investigations, which form the basis for the above conclusions, have naturally caused an elaborate study of the movements of warm air which first had to be made visible. This was done by the use of smoke bombs, and recorded by photography, using ordinary cameras. As a single picture does not always show all the results which can be seen with the naked eye, several motion picture cameras were used in a number of cases in order to check, compare, and confirm previous results.

From all this data, together with temperature determinations in various types of buildings, a number of diagrams have been prepared, some of which are reproduced.

Before taking up the circulation diagram, however, there are certain principles based, it is believed, on well known and accepted laws which it would be well to state.

1. That little energy is required to move a body of air horizontally through its own temperature stratum as compared to the much greater energy required to move hot air downward against the resistance of a cold air stratum, or to move cold air upward against gravity into a stratum of less dense air.
2. That heated air or air warmed above the surrounding temperature, will follow its natural tendency to go upward unless controlled, and that it may be controlled by a maintained velocity sufficient to overcome natural effects.
3. That the cold air stratum lying along the floor of a building cannot effectively be removed and carried upward through a warmer air stratum to a point above the working zone except by the use of ducts or conduits, even though mechanical means be used to create velocity or pressure, or both.
4. That a cold air stratum may be moved horizontally from along the floor by mechanical means or stack effect, provided there is created a sufficient induced velocity in an enclosure carried down to, or near, the floor line.
5. That the B.t.u., or amount of heat secured from any given heating surface, increases as the velocity of the air over the surface increases. This is true within the limits of practical operation.
6. That the convection principle, or the circulation of heat laden air, through the zone to be warmed, is essential to the most efficient warming of that zone.
7. That blasts of hot air moving at appreciable velocities within the working zone must be avoided in the design of practical heating systems.

With these principles in mind, the significance of some of the diagrams and photographs shown can be better appreciated. Fig. 2 illustrates the circulation of heated air with a direct radiation system having open radiators or coils ordinarily employed in an industrial building, as demonstrated by smoke bomb tests. It was found to be almost impossible to get a photograph that really pictured what took place. This diagram, however, is a faithful representation of the resulting circulation. Of course, overheating of the upper part of the building results, with a consequent waste of fuel.

Fig. 3 shows the circulation obtained with a disc fan type of unit heater, having an outlet velocity of 400 ft. per minute, and suspended 12 ft. from the floor. The photograph, Fig. 4, shows this heater in action while Fig. 5 of the same heater, similarly placed, shows the addition of a 45 deg. deflector outlet. Fig. 6 is a photograph of the condition represented by Fig. 5.

Fig. 7 illustrates the same heater, similarly placed, but with discharge directed straight downward and Fig. 8 is a photograph of the arrangement diagrammed by Fig. 7.

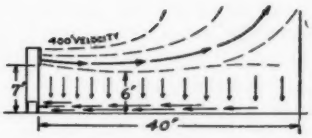

Fig. 14. Circulation of Floor Mounted Heater

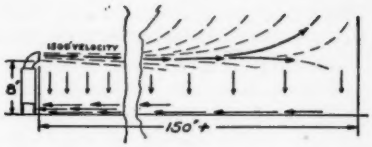

Fig. 15. Unit Operating with High Outlet Velocity

Fig. 9 portrays the circulation obtained with a heater also suspended 12 ft. from the floor, but with a housed centrifugal fan discharging at 1500 ft. per min. velocity with 60 deg. deflectors. Fig. 10 is a photograph of the conditions represented by Fig. 9.

The photograph, Fig. 11, was taken some minutes later, after the smoke had diffused through the entire building (200 ft. long by 60 ft. wide). There is a distinct line, which can be plainly seen, below which the smoke did not move while diffusing, showing that this diffusion and, therefore, the heating effect, beyond the direct range of the heater, occurred only in the upper part of the building.

With all of the above arrangements, except Fig. 9, it will be noted that the main current of heated air is upward from the heaters, and that no heated air penetrates the working zone far enough to mix with the stratum of cold air lying along the floor. Therefore, this cold stratum will receive heat only by radiation from the warm air above, except possibly from some minor air disturbance or eddy, caused by belts or machinery if present and in operation. Attention is called to the fact that the range, over which the heated air is distributed, is reduced as the discharge is directed more sharply downward. In Fig. 9 the outlet velocity of 1500 ft. per min., created by the centrifugal fan, was sufficient to carry the heated air to the floor, but as soon as its velocity was expended, it moved directly upward. This

Fig. 16. Floor Mounted Heater with High Outlet Velocity Immediately after Igniting Smoke Bomb

heater was placed in this position to show comparative results, but such a blast in the working zone would be objectionable in most places.

The range of distribution of this unit, while twice as great as in Fig. 3, is still not comparable with a floor mounted heater with centrifugal type of fan.

Fig. 12 shows a centrifugal fan type of unit heater suspended, with 1500 ft. per min. outlet velocity, and the arrows indicate the circulation that would be expected. This is not, however, the circulation that actually takes place. Fig. 13 is a photograph of what does happen. The velocity of the heated air is expended

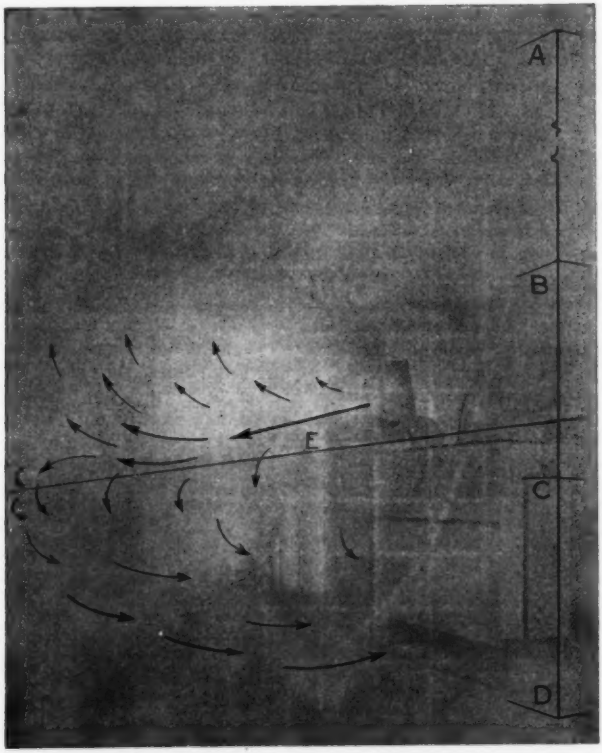

Fig. 17. Five Minutes after Ignition of Smoke Bomb

by the time it reaches the floor, and, before it loses its heat, being then uncontrolled and still hot, it rises straight upward toward the roof, where it is diffused. The heater draws air horizontally from the level in which the inlet of the heater occurs, as this is the path of least resistance. To draw lighter air from above, downward, or heavier air from below, upward, offers greater resistance.

Fig. 14 illustrates the circulation occurring with a floor mounted unit heater, from which a velocity of 400 ft. per min. is created by a disc fan, the range of this unit being limited by the outlet velocity. The overheating of the upper part of

the building will not be so great as if suspended. The low outlet velocity controls the heated air, against its natural tendency to rise, for a short distance only.

Fig. 15 indicates the value of a high outlet velocity; namely, to control the air blast and hold it as near as practicable to the working zone until its limit of distribution is reached. The range of this type of unit is, therefore, greater than others and tends toward less overheating of the upper part of the building.

Fig. 16 is a photograph of the unit diagrammed in Fig. 15, taken immediately after the smoke bomb was ignited, while Fig. 17 is a second photograph taken 5 min. later. Note diffusion of smoke into lower areas and in working zone.

Fig. 18. Suspended Unit with 500 Ft. Velocity and 45 Deg. Deflector Immediately after Ignition of Bomb

Fig. 18 is a photograph of a suspended unit having an outlet velocity 500 ft. per min. with outlets turned down 45 deg. and taken immediately after the smoke bomb was lighted, and Fig. 19 is the same unit 15 min. later. Note the absence of diffusion of smoke in the working zone, as compared to the diffusion created by the floor mounted, high outlet velocity unit heater, shown in Fig. 17, taken 5 min. after starting.

The degree of overheating in the upper part of a building depends on many factors, including the height of the building, the temperature difference between inside and outside, the amount and location of infiltration, the temperature, velocity and direction of the heated air leaving the heating equipment, and the location of the places at which the heated air is introduced. It is, therefore, impossible to

make a general statement of facts in regard to the amount of overheating that would be accurate except for one particular installation. In general, however, the conclusion must be reached that:

> Heating economy is dependent upon the extent to which the heaters are able to move the heat they deliver into the working zone, where it is useful, and allow as little of it as possible to escape into the upper areas, where it is wasted. Since floor mounted, high outlet velocity heaters accomplish this to the greatest degree possible without blasts in the working zone, they may be depended upon to heat the average modern industrial building with the least rise in temperature per foot in height from floor to ceiling, with the greatest

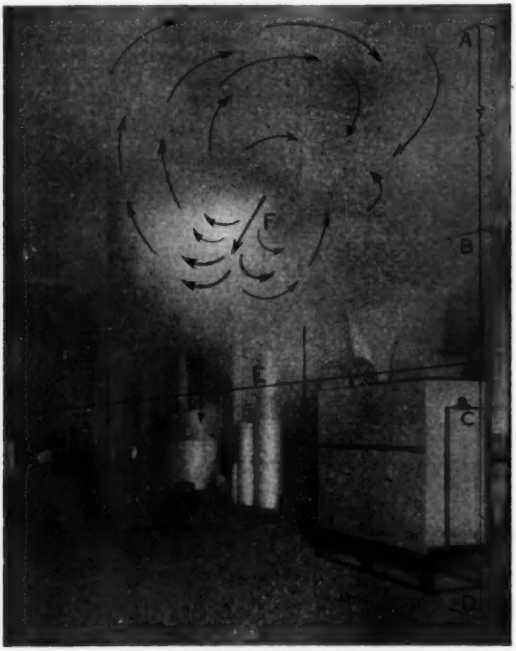

Fig. 19. Suspended Unit 15 Minutes after Ignition of Smoke Bomb

> heating economy. High outlet velocity allows the air to be moved long distances horizontally in its own temperature stratum, and this makes for fewer units of greater capacity, more widely spaced, with attendant simplification of piping layouts, fewer branches and fittings, and lower combined first cost.

While the writer and his associates have made many tests, observations, and investigations along this line, it is not felt that what has been done is the sum of all knowledge on this subject. It is only a beginning, and some authority—such as the Research Laboratory of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS—could well afford to undertake independent investigations, in order to determine more fully the principles which are suggested herein.

May the searching light of scientific research move onward, thus making it possible for the heating engineer to realize more fully his ideals, his duty to the public, and to mankind in general.

DISCUSSION

THORNTON LEWIS*: The paper which I am presenting deals with the circulation of warm air, secured by the use of unit heaters in industrial plants. In this connection, I am reminded of a certain lawyer, who, when considering any problem, always analyzed it by asking three questions, "What is it? Why is it? What of it?"

In discussing this paper, I am first going to ask the question, "What of it?"

We know that industrial plants can be heated by direct radiation, by blower systems, by suspended unit heaters and by floor-mounted unit heaters, and why should we not use any one of these systems, depending only upon our personal taste in making a selection. In other words, why should we spend all this time in discussing the various methods of heating and consequently air circulation.

The reason is just this—by the proper use of floor-mounted unit heaters, using high outlet velocities, it is possible to save from 15 to 30 per cent of the fuel used, over any of the other systems mentioned, and in some cases this saving may even be as great as 50 per cent. When we consider the tremendous amount of coal that is used for industrial plant heating, this saving is an enormous factor in our economic life, and the answer to the question "what of it" is fuel saving and conservation to the nation.

Why is it? The answer is proper air circulation. With this system of floor-mounted, high outlet velocity unit heaters, by which the air in the building is set in motion, a circulation is caused as far as 200 ft. from the unit, with no ducts, pipes or other distributing channels. It is quite important that we understand the causes of air circulation, and the factors which affect and govern it. The first principle announced on page 454 of the June JOURNAL is a most important and fundamental law. We might say that this is not a new law, for it is certainly true that it is based on old principles, which are now restated in the light of progress in heating systems. It is new only in the sense that all new things are only old principles restated.

What is it? The answer is found in the paper and the accompanying slides.

H. B. ADDINGTON (WRITTEN): The paper just presented by Thornton Lewis opens a field for discussion and investigation very wide and very important in its scope. Mr. Lewis and his associates are to be commended for their direct approach to the questions involved and their masterful employment of engineering fundamentals in seeking the answers to these questions. In all cases, such as this, where a proof is attempted based partly on presumptive theoretical explanations of observations, questions of conclusions always arise and it is to be hoped that Mr. Lewis and others will continue this subject until conclusions shall be reached to which no questions can arise.

The tests described by Mr. Lewis are open to question in the assumption that the smoke-travel is identical with the heat-travel. Smoke is carried by the velocity of the air-stream into which it is introduced against its tendency to rise

* President of York Heating and Ventilating Corp.

regardless of its own temperature. Smoke is carried by the air-stream through air strata into which it diffuses very little whereas the heat in the air stream is diffused to surrounding strata slightly by diffusion of the air stream and very largely by contact along the surface which is, of course, in a very turbulent condition. When the air-stream is arrested by contact with solid barriers or opposing air currents, diffusion occurs rapidly, heat is transferred, and the air takes a resultant course at very low velocity whereas smoke thus released from the control of a high velocity current, rises. The foregoing presumptions are so well borne out by accepted facts as to throw grave doubt upon the application of a smoke test to the diffusion of heat.

On the other hand, our experience and numerous partial tests at hand derived from temperature readings at numerous points about a room heated with fan and heater units set as in Fig. 5 for instance, indicate that heat is transmitted downward much farther than Mr. Lewis' tests would admit as possible. We believe our method of attack is to be preferred over the smoke-test method because we measure the heat at all points directly by thermometers and trace all air currents set up in the room by anemometers. This is a more direct method and although it is much more complicated, it is less questionable in results.

In conclusion, we echo Mr. Lewis' suggestion that this question is worthy the attention of the Research Laboratory of the AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS and acknowledge our indebtedness to him and his associates for the facts they have given to the engineering profession by these tests and report.

F. J. MCMORRAN (WRITTEN): The use of unit heaters for industrial buildings has taken its rightful place in the industry. Needless to say, there have been installations made which were not successful in maintaining satisfactory conditions. These failures have been due to disregard or misunderstanding of the basic principles involved in the application of the unit heater system. For this reason Mr. Lewis is to be congratulated on the work he has done in giving us this demonstration of the circulation of air under various conditions of direction and velocity.

It is well to bear in mind at all times the fact that the result desired is air at the proper temperature in the working zone and that uniformity of temperature is secured by movement of the air.

If a number of blocks are piled up one on top of another we have an arrangement similar to the air condition existing in a building; each block representing a stratum or level of air. Then by removing the bottom block, putting it on top of the pile and repeating the operation we see that the block originally on top passes down through the various levels to the bottom. The floor type unit heater taking air at or near the floor level, warming it and discharging it out above the working zone, is therefore, the logical arrangement and complies with the natural movement of the air. This then leaves us only the discharged air to control for horizontal travel and distribution.

The tests on which Mr. Lewis based his paper show very clearly the necessity for comparatively high discharge velocity and a slight downward pitch of the air stream. I have known cases of faulty distribution being traced to horizontal air discharge and being corrected by giving a slight downward pitch to the outlets. In these cases we also maintained sufficiently high outlet velocity. The degree of pitch necessary varies inversely as the outlet velocity but high velocity is absolutely essential for maximum distribution and prevention of interference by roof or ceiling construction.

This question of the effect of roof construction is very important. High roofs or those of monitor or saw-tooth construction have a decided tendency to interfere with the distribution. Roof trusses also act as screens which form pockets and hinder distribution. High discharge velocity will effectively overcome these influences and has done so in numerous installations. With 1000 ft. outlet velocity we have secured good distribution over distances up to 150 ft. from the heater with several intervening monitors in the roof and the accompanying trusses below the roof.

The distance over which the air can be spread horizontally seems to be between 10 and 15 ft. for every 100 ft. outlet velocity. This is based on approximately 135 deg. outlet temperature and apparently higher outlet temperatures decrease the area that can be covered because of the greater tendency of the air to rise to the roof. The foregoing statements refer to floor type heater installations maintaining a flow of air off the floor. Ceiling type units drawing air from the upper levels increase all the hazards due to roof construction and the natural tendency of the heated air to rise. It is also desirable to discharge the air in well defined form as from a pipe or an elbow.

Knowing that large areas can be effectively covered, then the logical use of heaters is in large units because of the resulting economies. It is practical to build units having capacities up to 2,000,000 B.t.u. with air entering at 60 deg. and steam at 5 lb. pressure. The floor type unit taking the air off at the floor level is seen to have decided advantages in the matter of circulation and distribution. In addition, it has a greater heating capacity for a given heating surface and air volume because of its air being taken in at a lower temperature. A unit taking air off the floor at 60 deg. has 10 per cent greater heating capacity than it would have if mounted near the ceiling where it would take in air at 75 deg. Tests indicate that in the average industrial building the temperature at the ceiling would exceed 75 deg. if ceiling type units were used.

In closing, I also hope that further research and investigation will enable us to better analyze the conditions and make self evident the principles involved in the application of the unit system of heating.

F. R. STILL (WRITTEN): If there is one thing more than another for which this Society has attained notoriety, it is the apparent difference of opinion among its own members on many phases of engineering relating to the heating and ventilation of buildings and that is illustrated in the comments on this paper.

While the paper submitted by Mr. Lewis is an interesting contribution to the records of the Society, and while some of the photographic cuts show quite clearly how air circulates with suspended units for both high and low velocities, also with floor mounted, *high velocity* units, he failed to show how the same results can be accomplished with floor mounted, *low velocity units*. Had he displayed photographs of the latter, the observer would have been unable to distinguish any difference in their appearance; therefore, he had to resort to line drawings with "trained arrows" to support his theories regarding the advantages of *high velocities*.

Of course, we all know the objections to high air velocities, the discomfort ensuing if a blast of air strikes us no matter when, where or how. Even if it strikes a wall, column or some object in the room and is deflected onto us, it is quite as objectionable at high velocity as though it blew directly onto us, whereas air driven at low velocity avoids all such discomforts, and that is why most of the industrial heating units made today are low velocity units. Any maker of such units is in a position to furnish either high or low velocity types; if the high velocity types had any such advantages as the author of the paper tried to demon-

strate, it would be the most natural thing for all to furnish high velocity outfits. Experience has shown that they are not alone objectionable, but they are likewise more costly to operate besides accomplishing nothing that cannot be attained with the low velocity type.

Smoke tests may show air motion, but they do not show heat distribution nor diffusion. A gas at high temperature is lighter, and being admitted to another heavier gas at low temperature, immediately sets about to equalize the volumes, thus distributing the heat according to the pressure of the atmosphere at different altitudes. In other words, the "Law of Charles" applies here as well as in any other problem of the mixture of two gases.

Air motion may quicken the diffusion of heat under some circumstances, but it never adds anything to the effectiveness of the distribution except as to the length of time it may take to bring about certain results. Air motion also assists convection, which is recognized as more efficient than is radiant heat. We commonly think of convection in its application to the passage of air over heating surfaces, but it has a converse application by the air giving up heat to the cold surfaces of a building. This is why a building heats more quickly with air in motion than it does when there is no air motion.

Many of the problems which the author mentioned during his talk while on the floor at the last meeting, but which are not referred to in his paper, were solved by high velocities only because the units were improperly placed. Whenever the units have to be located some considerable distance above the floor, we would call his attention to the paper presented at the last Annual Meeting (January, 1926, JOURNAL) by Prof. J. E. Emswiler, entitled "The Neutral Zone in Ventilation." If the author has not already had the experience, he will ultimately find that infiltration has a lot more to do with the unsatisfactory heating of the lower portion of a building than anything else, and that it has a greater effect on the results when the units are placed some distance above the floor than when they are near the floor. We have had experiences where no amount of velocity or heating capacity in the apparatus would effectively penetrate the *Neutral Zone* referred to by Professor Emswiler. It is our opinion that Professor Emswiler has made a real contribution to the solution of this puzzling problem, and in doing so he has strapped the subject of a lot of "trade bunk."

HENRY BAETZ: I have prepared a few comments on unit heaters in line with the very excellent paper by Mr. Lewis, on this subject which is of so much interest today. In Mr. Lewis' paper it is suggested that heating engineers do not seem to have a proper understanding of the unit method in which there are no distributing ducts.

My experience, covering an uninterrupted period of 30 years, with engineers was that I could make little or no progress with them on the idea of warming large spaces without distributing ducts. The present popularity of the unit heating idea resulted from years of experiment and development.

Many successful installations caused a general acceptance of the method by engineers, though their attitude of natural conservatism toward what might be termed a radical innovation is well understood.

The innovation was a radical one, not because anything very remarkable had been discovered, but because it entirely eliminated the duct work, the designing of which required the best engineering skill in working out the plan according to intricate and technical rules. With the unit system came simplicity and economy, but judgment and engineering skill were still required to obtain an efficient

heating system. Right here I would like to relate a personal experience of only a little over a year ago where a considerable sum was saved in heating a factory.

An industrial institution of great magnitude had under construction a number of large buildings aggregating 35 acres under roof. The engineers had prepared a very elaborate lay-out of underground ducts through which the heated air was to be carried from a central plant, and this plan had been approved after adoption. The engineer in charge, however, was fortunately a man of broad mind, and well fitted for the responsible position which he filled. He harkened to the arguments put before him on the virtues of the unit system and threw aside his own elaborate creation for the simple one of using 100 unit heaters. This actually resulted in a saving of $150,000 to his company.

The late Prof. John R. Allen, in his valuable research work for the Society, pointed out the difference that exists between radiant heat and heat by convection. This difference is fundamental and has a certain bearing on the question of methods of distributing heat.

It will not be necessary to elaborate on the peculiarities of the two kinds of heat, except to remind that in a general way radiant heat passes from a radiator in the form of rays like light rays. They travel through the air without affecting its temperature. However, they do increase the temperature of a body against which they impinge. Heat by convection passes directly from the surface of the radiator to the air which brushes in contact with its surface.

Radiant heat is the heat which may be said to be the most prominent in a direct heating system because it is the heat one feels when approaching a radiator, but in quantity it amounts to considerably less than the output of heat by convection from the same radiator. Because of its great prominence, this radiant heat has largely dictated the location and number of radiators in a direct radiating system. In the fan system of heating, radiant heat should play no part at all, but nevertheless it did at one time play a part. The original designers of the fan heating distributing system sought to produce the same result on the factory floor that direct heating produced and they simply placed an outlet at every point where a direct radiator would have been placed had the system been direct.

Radiant heat has ever been a pleasant thing for man. First it came to him from the sun alone. Then with the discovery of fire making he enjoyed its warm rays as the fire lighted up his forest home. After that came the fire place in his rude hut, next the family heating stove, and finally the sizzling radiator. Down through the ages man has enjoyed the soothing radiant rays of warmth from these various sources and, while the means and methods change, the radiant heat remains the same.

Man's association with it has been so intimate that he seems to act toward it now by instinct. You have observed how this instinct crops out whenever he gets within the range of its seductive rays. He basks in the most contented and pleased attitudes and it is within its influence that he is socially at his best. There is, however, one significant thing about man's association with radiant heat that is of much importance in factory heating. The rays of radiant heat seem to have something about them that dulls energetic action—that seems to make people feel lazy and not inclined to work. When man is lounging about, taking it easy, or "day dreaming," he is invariably within the range of radiant heat. It is obvious, of course, that in work shops laziness must not be encouraged and therefore radiant heat should be allowed sparingly. The unit heater does its work effectively and gives no radiant heat.

The floor mounted unit heater consists of a heating coil inclosed in a sheet

steel jacket, with which a blower or fan is connected. The unit draws the air from near the floor or lower part of the room and forces it in contact with the heating coil where it gathers its proper quota of B.t.u's. Then it is forced out of the top at a substantial velocity in a horizontal direction over head and in a general way toward the exposed walls. At the cold exposed walls the heated air delivers the necessary B.t.u., then, in accord with the law of gravity, it falls to the floor from whence by suction of the fan in the heater it travels back to the heater where it again passes over the coils and is reloaded with B.t.u. Meanwhile the small quantity of fresh outdoor air which has filtered into the building to replace what has leaked out becomes mixed with the slowly moving room air. This new air is usually sufficient for ventilation, but more can be supplied to the system if desired. Thus the natural laws have been followed with the aid of the fan to obtain an even distribution of temperature. The action of the fan not only assists the horizontal movements of the air discharged from the heater, but this moving air drags along with it the adjacent air finally moving the entire body of air in a continuous but imperceptible manner and it affects every nook and corner.

How this movement of air body occurs may be demonstrated with a circular vessel filled with liquid. Let the liquid body be quiescent. Then insert an ordinary lead pencil and move it parallel with the circular wall. In a few turns the entire body will be in motion, and in complete harmony. The air in a room acts in exactly the same manner and on the same principle, in fact, the same action of air is more quickly responsive in following other air in motion than liquid would be. On the other hand let us suppose that instead of moving the pencil in a continuous circle it is criss-crossed indiscriminately instead, the result would be that the body of liquid itself would remain largely quiescent and movement would occur only where the pencil touched, because the movement in one direction of the pencil would counteract the movement in another direction and such is substantially the conditions when numerous outlets discharge heated air in various directions.

It is for that reason that a minimum number of large capacity heaters will give far better results than numerous small ones scattered about. The question then comes up, How long a distance from the building wall to the heater would it be safe to depend on this movement of air, so that the desired temperature would be maintained? The answer to it is that it is impossible to state a specific limit in feet because that would depend on so many things which vary in every building.

An installation where the distance is 300 ft. from the far wall to the heater has been operating for 20 years. In this room bench work is done and the temperature is even.

Experience is what counts for everything in this matter of proper location for heaters, and as a general rule my preference is to discharge the heated air toward the exposed walls.

In connection with unit heaters for industrial plants much has been said about floor space, and it seems to me the term "floor space" has become a sort of catch phrase rather than representing a substantial fact. A successful installation of a unit heater must, in my opinion, provide for drawing the air from near the floor. If this is not done, while the job may work, it is my belief that it will not be an economical one for operation. When the heaters are high up in the air, with a recirculating pipe reaching down near the floor, little has been saved by elevating the heaters. I make the assertion that, properly installed, a floor type of unit heater will deprive the factory owner of less usable floor space than any other

heating method the apparatus of which is within the room, for with a floor space of 10,000 sq. ft. the heater will not take more than 10 or 12 sq. ft.

W. H. CARRIER: I want to discuss this paper, not just simply to get up and say something, but there are certain factors here that I think the Society should have brought to their attention. I do not agree altogether with the broad conclusions of the author. Mr. Lewis has done a very great service to this Society in bringing a method of approach and a study of this subject that I believe is very valuable.

Many of his conclusions I believe are very sound, particularly those pertaining to distribution—that the tendency of air is to distribute in a plane corresponding to its temperature.

There are other factors, however, which I believe, if they have not been overlooked, have not been emphasized and may give a wrong impression to many. There are certain phenomena that occur in distribution of air that his tests have not brought out and we do not want to draw too hasty conclusions from data based on a single type of installation.

We are all familiar with the tendency of hot air to stratify as has been brought out, but we must be careful in considering systems of distribution to not generalize and apply the same reasoning to distribution of cool air that we apply to the distribution of warm air. It is not the distribution of air that Mr. Lewis has discussed, it is the distribution of warm air. When you come to the distribution of cool air you have an entirely different phenomenon.

There are many things that come in the distribution of warm air that do not come in with cool. For example, drafts. In the distribution of cool air you have to be very careful about the avoidance of drafts which in the distribution of warm air seldom cause much worry. The same general law that Mr. Lewis brought out applies but the effect is reversed as the cool air falls rapidly while the warm air rises, and a system that might answer very well, or would be ideal, for warm air would be entirely impossible for the distribution of cool air.

Now, there is another general law and that is that any outlet distributing air, whether warm or cold, doesn't merely blow that air and distribute it over the room. But, whenever you discharge air through an outlet you draw with it a considerable volume of room air. Sometimes this is a very large percentage of the total air moved, as much as four or five times the air introduced in extreme cases. This is a phenomenon that heating engineers have long failed to fully appreciate and it is very vital in its effect on ventilation, on heating, and in drying. The amount of air that is set in motion by ejector effect, by dragging effect, by viscous action, or whatever you want to call it, varies considerably. It depends first upon the size of the outlets, and second upon the air velocity. It also depends to some extent upon the air temperature. There are a great many laws in connection with this distribution that are not well known and eventually should receive the attention of our Research Laboratory to determine what actually takes place; that is, the quantitative analysis of the effect of a current of air introduced in any part of a room upon the distribution and upon the amount of air that is dragged along with it. In ventilation we usually think of distributing the air we are putting in, say 50,000 cu. ft. of air in a room, and we think that is the only air being handled. More than likely we are setting in motion 100,000 or 150,000 cu. ft. of air, and that is our real displacement. The study of these secondary air currents is very interesting.

Some years ago I was led to notice the effect of certain outlets in a drying room, and I noticed that a return current took place. Well it was reasonable, but I

was surprised at its uniformity and also by the fact that these return currents were in opposite directions to the air that was being introduced. By the development of the principles thus observed, we were able to design the ejector system for processing and drying materials which we believe has been very valuable.

Another point that should be brought out in reference to this paper is that haphazard distribution of air has comparatively small effect in obtaining uniformity in contrast to that obtained by a systematic introduction of air, whether you are employing unit heaters or a distributing duct. As an illustration, if you will place a row of outlets across one end of a room and have this series of outlets all pointing in one direction toward the farther end of the room you will find that you will get a rotary action, a systematic movement of the air of the entire room. On the other hand, if you take this same number of outlets and have them discharge in different directions, putting them here and there, you do not get the same systematic effect. They are not working together. It is like a lot of men trying to pull a load and each pulling in a different direction. You get an entirely different effect both in distribution and stratification. The same principle holds true in the arrangement of unit heaters in large buildings. If you have a systematic arrangement of these heaters in relation to their direction of discharge it should follow, in accordance with all observations of duct outlets, that you would get a much better movement of the entire air of the room and much less tendency to stratification than if they are arranged with variable directions of discharge. Even though the velocity of the unit heaters is low in certain types there is quite an agitation produced in the room and there is a movement of a considerable volume of air besides the volume of air that is being introduced.

There are, with unit heaters as well as with the old duct system of air delivery, two ways of obtaining distribution and overcoming stratification. In both cases there are the same general principles to be observed. You want as uniform temperatures as possible in every part of the room. You want to avoid stratification in so far as possible whether you are heating, cooling, or humidifying. Distribution is the essential thing in all fan system work of whatever type, whether in a heating system employing unit heaters or in an air conditioning system with elaborate duct work. That is really a vital factor which is too little understood and the importance of which is so often overlooked.

You can accomplish this thorough distribution of the air in two ways. *First*, by handling a small volume of air at a high temperature difference and a high outlet velocity which will effect the thorough distribution of air and mixing with the air of the room. *Second*, by the use of a very large volume of air at a relatively small temperature difference and much lower velocity. Either method, if properly applied, will obtain essentially the same results so that we can hardly be dogmatic and say that we must have high velocity in order to get the distribution or, on the other hand, say we must handle very large volumes at small temperature difference in order to get distribution. The air velocity and the number of outlets employed must be proportioned suitably to the air volumes handled and that is about all that is necessary.

We must not conclude because there is one way of accomplishing certain results that there are no other ways if properly applied that will accomplish the same thing because we find that is usually the case.

There are many factors in the proportioning of outlets for which no general law has been determined but only certain empirical values obtained from experience.

But, velocities as high as 1500 ft. per minute can be used in cool air ventilation without producing drafts and it will work equally well in the distribution of warm air.

The point that I wish to bring out is that we do not want to draw too broad conclusions from one set of data or from one type of installation. There are other things which may happen under other conditions which we have not taken into consideration and, by changing the conditions, the results observed may be completely reversed.

There is another consideration in the application of unit heaters as to the type of building to which it is to be applied. If you have a single story building of loose construction and high roof, there will be a great amount of infiltration and consequently great difficulty from stratification. With this type of building, unit heaters on the floor and fairly high velocities will be the only type that could be considered and Mr. Lewis' experiments and deductions become most important. On the other hand, where you have a well constructed building of possibly several stories then the difficulty from stratification is greatly minimized and the building can be heated satisfactorily in all probability with the equipment that Mr. Lewis' experiments would indicate to be poorly adapted when applied to the first type of building; so that again in most instances the type of apparatus chosen in reference to the building construction, as these two types, demand quite different treatment.

W. A. ROWE: Mr. Lewis' paper is a valuable contribution to the art of heating by means of unit heaters. It is especially appropriate at this time, because of the tremendous increase in the use of this method of heating. There are several points worthy of further discussion. In the first place, maintaining a suitable temperature at the breathing zone seems to require the discharge of the warm air horizontally, as close to the floor as possible.

The second point concerns the necessity for a re-circulating means to remove the colder strata of air at the floor line, in order that it will be displaced by the warmer air in the course of its circulation through the room. These two conclusions seem to be axiomatic. Experience has confirmed the correctness of each.

The third suggestion in the paper, relative to the necessity of high outlet velocities, has not been proven. In the illustrations used, I note Fig. 14, which is a diagram of the expected circulation of air, with a floor mounted heater of the disc fan type. Our experience indicates that the resultant condition, after a unit of this type is in operation for some time, will be but little different from that shown in Fig. 17, showing the diffusion with a similar type of heater, but with high outlet velocities. It would have been desirable could a similar exhibit been provided with the disc fan unit as well, after it had been in operation a short time.

There is one further point, namely that concerning drafts. Using the floor mounted type with recirculation causes a noticeable movement of sensibly cool air at the floor line in the immediate proximity of the unit. If there are operators working close to the unit, the movement of air around their lower limbs is sometimes so noticeable as to be distinctly uncomfortable. This will even result in night sweating of the lower limbs. While therefore, this method of heating, or recirculation, may be very satisfactory in buildings of relatively low occupancy, when it is used in more crowded quarters we have found the drafty condition can be immediately corrected by a reversal of the direction of air flow. This also results in a more uniform temperature in the vicinity of the unit, although it does not appear to make so great a difference at more remote distances. This seems to fall in line also with the conclusion first mentioned in the paper, of the desirability of having

a horizontal discharge as close to the floor line as possible. When warmed air is discharged at a moderate velocity at the floor line it imparts a most comfortable sensation of warmth on the feet of the occupants, and makes possible a lower average temperature of the building, with an equal sensation of warmth, for what we really aim to accomplish is warming the occupant, rather than the air of the room.

In conclusion, would say that Mr. Lewis has opened up a very interesting subject, and one worthy of further investigation. It would be fortunate indeed if our own Research Laboratory could devote some of the time to it, so that we may learn the correct relative values to assign to the different factors involved. These might probably include, besides temperatures, air velocities and direction of discharge, the effects of room height, or the relation between point of discharge and the neutral zone of the room, together with the whole theory of the stratification of air.

R. C. BOLSINGER: Mr. Lewis, in discussing illustration Fig. 19, stated that the air below line *E* was heated by radiation from the air above line *E*. I would like to ask Mr. Lewis if it is possible to heat air by radiation.

C. A. BULKELEY: I wonder if those present realize the tremendous amount of work that Mr. Lewis and his organization have had to do in order to present definite data for our consideration. We believe that efficiency of research work such as he has done along this line probably runs from 10 to 15 per cent. He made the statement that 15 or 20 tests were made for one that he has reported. Mr. Lewis has made a real contribution to the Society by bringing this subject up at this time. Heating by unit ventilation has only been scratched on the surface. I believe it will become eventually a recognized method of factory heating.

With reference to Mr. Carrier's statement regarding return of air, we have found such to be true in our work. I want to say to Mr. Lewis that this return current of air near the floor line being blended with the hotter air which he throws into a room at high velocity at higher levels will decrease the tendency of the warmer air to rise to the ceiling.

One other thing we would like to mention, and that is, it has been our dream that some day this unit system might be applied to air conditioning. So far as we know it has never been tried out on any extensive scale. We believe that this same principle of unit equipment might be applied to air conditioning to both humidify and dehumidify. The scheme of discharging air at high velocity drawn from near the floor as described by Mr. Lewis with his unit heater, results in improved efficiency in heating. An almost corresponding improvement in efficiency of air conditioning might be obtained with a unit type of air conditioning unit.

G. E. OTIS: I would like to endorse what Mr. Carrier said about the movement of air, by what we have been pleased to term aspirating effect. In employing the high velocity vertical air discharge jet in units for public building work we have noticed a decided current of air across the floor, notwithstanding the fact that we employ no recirculating means. This movement of air in the lower stratum is induced entirely by the velocity of the vertical jet.

THORNTON LEWIS: I would like to answer Mr. Bolsinger first as he asked a direct question. What I intended to convey by what I said, about the transfer of heat below the Line *E* in Fig. 19 is that there is an actual transfer of heat from the heat contained in the warm air above that line to the cooler air below the line. You can call it radiation or call it what you want, you get a heat transfer but it is

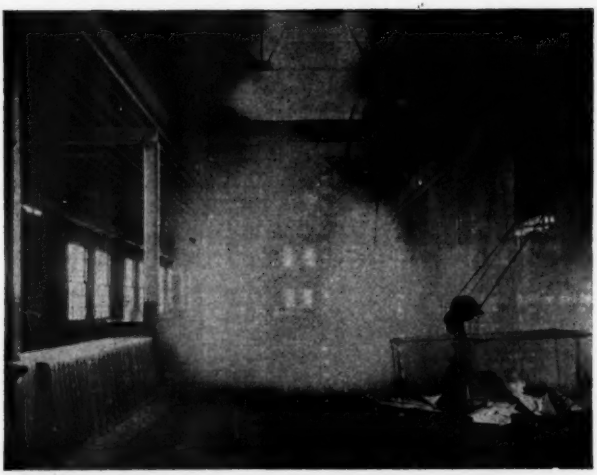

FIG 20. UNIT BLOWING AIR DOWN AND UNDERNEATH FAN

an inefficient heat transfer when compared to the transfer of heat from prime heating surface by having cool air drawn over it within the unit.

Now, in regard to what Mr. Carrier and Mr. Rowe had to say: I was very much interested to note that Mr. Carrier agreed with me on high outlet velocities and Mr. Rowe on the other basic principles stated, but did not on high outlet ve-

FIG. 21. UNIT HEATER WITH SMOKE BOMB RAISED ABOVE INLET

locities. I submit for your consideration, when two such distinguished experts differ, that I may be somewhere near right.

I feel that Mr. Baetz' explanation of the history of this industry is very interesting. There is no man better qualified to tell us of the history for I think he has been in the business longer than anybody else, and he is qualified to speak on this subject.

He spoke of a building three hundred feet long which was heated with a floor mounted heater. I know of an installation in Camden, New Jersey, which is 346 feet long, which has a unit heater at each end, where in mild weather only one heater is used. Circulation in mild weather is just as good at the farther wall, 346 feet away, and an even temperature is maintained at any height above the floor.

The square feet of floor space occupied by the unit compared to other systems,

FIG. 22. RESULT WITH SMOKE BOMB IGNITED AT SIDE OF HEATER

was mentioned by Mr. Baetz. I want to bring out one point for some members who may not be familiar with unit heating. Suppose you do not take any credit for the floor space saved by the elimination of radiators, but charge entirely to the unit heating system the floor space occupied by floor mounted heaters, and suppose that you charge that system with the highest possible building cost per square foot that you can have, you return sixty per cent on your investment the first year. You can afford to build your building larger to put in the floor mounted type of unit heaters in order to make possible the great saving in operating costs.

Another thing, in the published paper, our printer has made a swap of titles for Figs. 9 and 7. That is perfectly obvious from the other things that have been brought out, but I want to mention it. The cost of operation figures, for which slides were shown on the screen, are not based on opinion only. They are general; they vary in different buildings, but they are confirmed by a number of tests, by comparisons of cost of heating buildings of certain sizes and construction with

various systems, and I think you will find that they will average up on ordinary industrial buildings unless you go to a building twenty-five by forty, which is a very small building.

In regard to Mr. Addington's written discussion in which he spoke of the smoke test as not necessarily duplicating what happens in the way of circulation and heat transfer: I hope you gentlemen do not think that I would come before you and present these photographs and diagrams of what happened unless they had been checked by numbers of tests in which readings were taken, as many as thirty readings in a floor area of 200 ft. × 80 ft. and at various heights, so that while I am not giving you actual figures for temperature readings, for the mass of data that we have already accumulated would fill a library, and it varies with

FIG. 23. DISTRIBUTION AFTER SMOKE BOMB HAS BURNED OUT

different types of buildings, yet the fact that there is a saving by reducing the temperature in the top of the building has all been confirmed by any number of tests, and all you gentlemen have to do to satisfy yourselves is make a few of them, and you will be surprised. Take two or three thermometers in your own office, no matter how it is heated; put one on the floor and one three feet up and one near the ceiling, and see what you get.

Now, in regard to what Mr. Carrier said about the amount of room air induced by the outlet, depending on the perimeter: I agree with him on that, absolutely. For this reason, it has been our practice to use a number of outlets in which the total perimeter is more than with one outlet of the same area. Then he mentioned that the outlets must all blow in one direction. You have to take that statement with a good many conditions. If we put a unit heater in the center of this room and blow in each of the four directions, haven't we substantially four different sections, and we are not blowing any cross currents in any one section, so that you have substantially your room divided into four parts, and in each part you are obtaining circulation only in one way. If you have a large building, you can put one unit in the center, blow in each direction and take care of a building four

hundred feet long and four hundred feet wide, while if you could not place one in the center but had to place it at the ends of the room, you have a different condition, and would have to use two or more units.

So long as your outlets do not blow against or across each other, you will not have any trouble with cross currents. This has been demonstrated by smoke bomb tests.

Here is shown in Fig. 20, a ceiling type of unit which blows the air down and underneath the fan. You will note the smoke bomb there, and that the air reached the floor, turned and went up again. The limit of distribution was about twelve feet from the center of the unit in each direction, making a circle, you might say, twenty-four feet in diameter.

Now, I want to come back to the one principle that has been brought out—air will move horizontally most easily within its own temperature stratum. (See Fig. 1, June, 1926, Journal, p. 452.) It is sometimes said that overhead heaters mounted above, take the warm air from the top of the building, and put it at the floor level where we want it.

Here in Fig. 21 a unit heater in operation is shown, but the smoke bomb was raised 3 feet 6 in. above the inlet of the heater when it was ignited. The smoke ascended from the bomb directly to the roof, and the unit immediately below had no effect upon it, so that if you are going to try to draw the warm air from the top of your building (I don't know what it is doing there, nor where it comes from, if it is there), and you want to draw it down, you have to put the inlet of your unit within three feet of your roof; otherwise, the unit will draw the air from where the inlet is.

Here is the bomb moved over to the side but in the zone within 3 ft. above the unit as shown in Fig. 22 and there, while some of the smoke went up, most of it came to the unit heater and went down, showing that the movement of warm air is horizontal within its own temperature stratum.

Now, after the smoke bomb had burned out, this picture, Fig. 23, was taken. You see where the smoke was, and again, we find it all in the top, none in the lower area. Even though the air had been blown down to the floor, the moment it got there the velocity was expended and the air went straight up again.

No. 754

FRICTION OF WATER IN ELBOWS

By F. E. Giesecke,[1] Austin, Texas

MEMBER

SEVERAL years ago the writer conducted a series of tests to determine the friction of water in standard 90° elbows. The results of these tests were published in University of Texas Bulletin No. 1759 and are reproduced in Fig. 1. The coefficients determined for the several pipe sizes are not as uniform

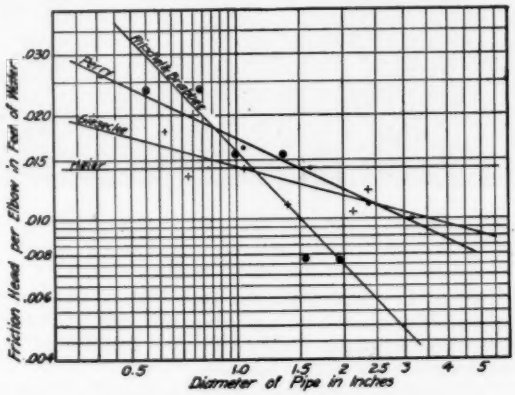

Fig. 1. Comparison of Coefficients of Friction in 90° Elbows

as they should be and the resulting average values are, therefore, not as accurate as desirable.

Since publishing these results the writer learned that the coefficients used by Rietschel and Brabbée (*Leitfaden*, 5th edition), to determine the friction in standard 90° elbows differ materially from those which he had determined. He also learned that Meier (Mechanics of Heating and Ventilation), assumes that the

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Paper presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, Lexington, Ky., May, 1926.

variation in the friction of water in elbows with the diameter of the pipe is so small that it may be neglected in calculations relating to hot-water heating systems. Also that tests to determine the friction of water in elbows have been conducted at Lafayette College by Prof. L. Perry and the results published in *Engineering News-Record*, May 29, 1924.

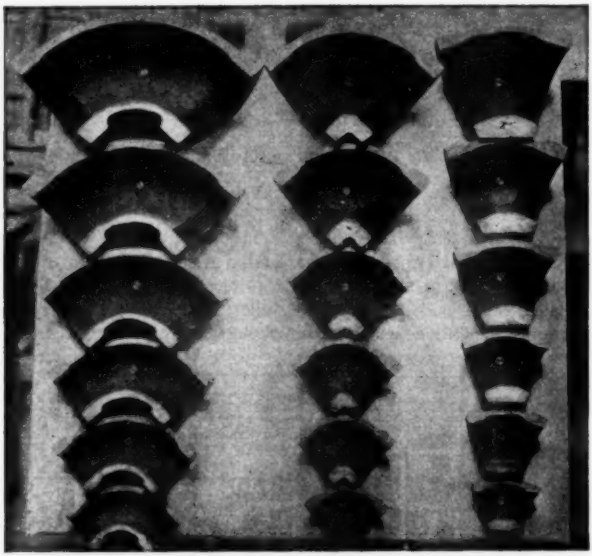

FIG. 2. SIZES AND TYPES OF ELBOWS TESTED
From 3-in. to 1-in., 90° long radius, 90° short radius, and 45° elbows.

The Rietschel and Brabbée values, the Perry values, and the Meier value are shown in Fig. 1 in comparison with each other and with those determined by the writer. The differences between the four groups of values are considerable and make a more accurate determination desirable.

In addition, the writer recently learned that certain large corporations prohibit the use of 90° elbows in the pipe lines of heating systems and require, instead, two 45° elbows and one nipple. This regulation is evidently based on the assumption that the friction in one 90° elbow is higher than that in two 45° elbows and one nipple.

The writer, therefore, decided to repeat his earlier tests on a larger scale and according to a more accurate method.

In order to secure elbows of a uniform character so that the results might not be affected by differences in the shapes of elbows produced by different manufacturers, the proposed investigation was submitted to Crane Co., who furnished free of charge the entire series of 90° short radius, 90° long radius, and 45° elbows needed for the test. Fig. 2 shows one of each size and type of elbow tested during this investigation.

The general arrangement of the set-up and of the method of conducting the tests will be clear from Figs. 3, 4, 5, and 6, supplemented by the accompanying explanation. To determine the friction in each of the three types of $1^1/_2$-in. elbows, the procedure was as follows:

The pipe line shown in Fig. 3 was set up and connected so that water could flow freely from the city water main through the line and into the weighing tank. The large tank shown in the illustration was connected to the system so that it served as a pressure regulating device and the velocity of flow through the line was controlled by a valve. The operator in charge of the regulating valve, located so that he could observe accurately the level of the water in the tank, could easily

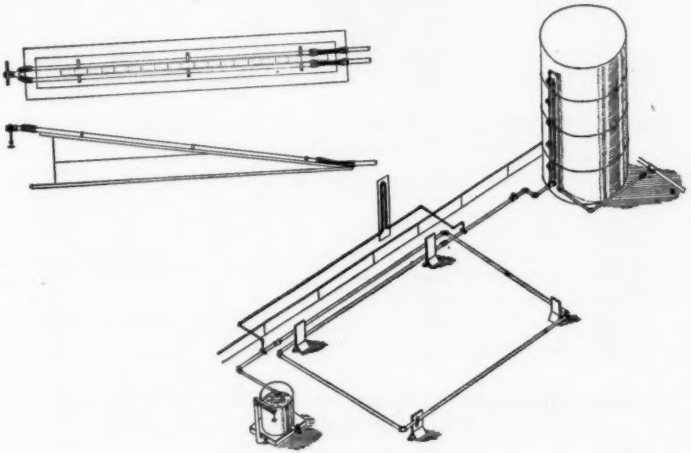

FIG. 3. SET-UP OF PIPE LINE FOR FIRST TEST OF 90° ELBOWS

keep the water at a constant level and consequently the pressure head of the system and the velocity of flow constant. The friction head was determined with a water manometer which was connected by means of two piezometer rings separated by 91 ft. of pipe and four standard 90° elbows. The velocity of the water in the pipe was found by weighing the quantity flowing in a given time and determining the actual internal diameter of the pipe. The observed data for the test are shown in Table I and by line F_1 in Fig. 7.

The set-up was then changed to that shown in Fig. 4 in which the piezometer rings were separated by the same 91 ft. of pipe used in the first set-up, but cut into shorter lengths so as to permit the use of 13 additional elbows. The test was repeated and the data shown in Table 2 and by line F_2 in Fig. 7 were secured.

In this manner the friction caused by 13 elbows is shown by the difference between lines F_2 and F_1. From this the friction in one standard 90° $1^1/_2$-in. elbow was found as follows:

The equation of line F_2 is

$$h = 0.7185\ V^{1.849} \qquad (1)$$

where h is the friction head in feet of water and
V is the velocity in feet per second.

TABLE 1. 91 FEET OF 1 1/2-IN. PIPE AND FOUR —90° SHORT RADIUS ELBOWS

Water Temperature = 80 deg. fahr.

Friction cm.	Water pounds	Time sec.	Velocity ft./sec.
124.8	100	38.8	2.954
105.7	100	42.+	2.729
100.5	100	43.+	2.665
95.6	100	44.8	2.558
88.5	100	46.2	2.481
74.0	125	63.8	2.245
64.0	100	55.2	2.076
55.0	100	60.0	1.91
47.0	100	65.8	1.742
46.2	100	66.4	1.726
38.0	100	73.0	1.57
37.0	100	74.6	1.536
20.8	100	101.2	1.132
20.3	100	102.8	1.115

TABLE 2. 91 FEET OF 1 1/2-IN. PIPE AND 17 —90° SHORT RADIUS ELBOWS

Water Temperature = 81 deg. fahr.

Friction cm.	Water pounds	Time sec.	Velocity ft./sec.
134.74	100	43.13	2.657
109.70	100	48.0	2.388
108.46	100	48.26	2.375
93.56	100	52.26	2.193
83.76	100	55.4	2.069
63.62	100	64.4	1.779
37.55	100	85.8	1.335
17.93	100	127.26	0.900
11.81	50	80.2	0.714

TABLE 3. 91 FEET OF 1 1/2-IN. PIPE AND 17 —90° LONG RADIUS ELBOWS

Water Temperature = 80 deg. fahr.

Friction cm.	Water pounds	Time sec.	Velocity ft./sec.
131.75	100	41.2	2.782
128.7	100	41.4	2.768
104.33	100	46.25	2.478
91.18	100	49.53	2.314
82.36	100	52.9	2.166
74.3	100	55.4	2.068
53.83	100	66.0	1.736
50.26	100	68.61	1.670
28.6	100	92.6	1.237
17.25	100	121.6	0.942
17.1	50	61.2	0.936

TABLE 4. 91 FEET OF 1 1/2-IN. PIPE AND 17 —45° ELBOWS

Water Temperature = 83 deg. fahr.

Friction cm.	Water pounds	Time sec.	Velocity ft./sec.
132.1	100	41.6	2.755
130.8	100	41.8	2.742
130.45	100	41.73	2.746
105.3	100	46.8	2.449
87.5	100	51.4	2.230
51.16	100	66.0	1.737
35.95	100	83.13	1.378
17.78	50	60.8	0.943
16.75	100	124.2	0.923

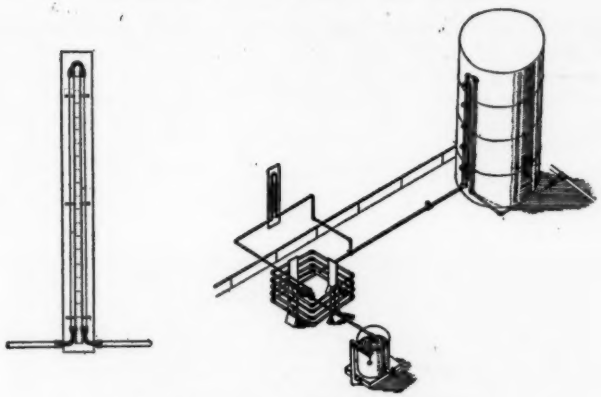

FIG. 4. SET-UP FOR TEST OF 90° ELBOWS

When the data of Table 2 were determined the water flowing through the system had a temperature of 81 deg. fahr.

Since the friction of water varies materially with the temperature, and since the range of temperature in the investigation was from 51 to 85 deg., all observed values were reduced to those which would probably have been obtained with 70 deg. water, by the method described in JOURNAL AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, December, 1924, as follows:

Equation 1 may be written in the general form $h = kV^n$ .....(2)

and value of k changed as follows:

Reynolds' number for $d = 1.6026$, $V = 1$ and $t = 81$ deg. is 14,675.
Reynolds' number for the same condition but $t = 70$ deg. is 12,720.

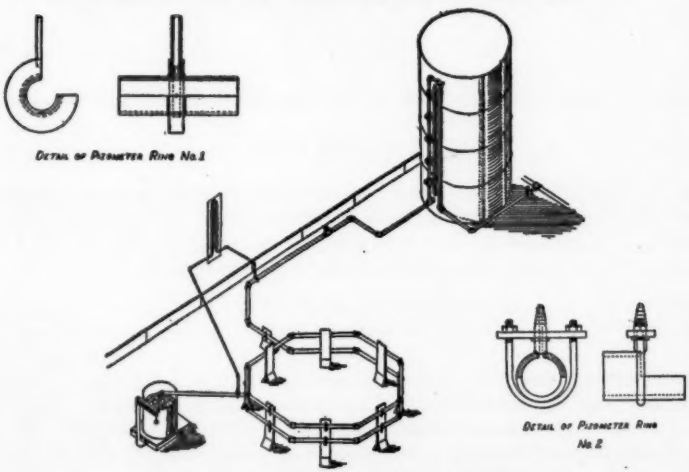

FIG. 5. SET-UP FOR TEST OF 45° ELBOWS

The corresponding values of f from the curve of Fig. 8 (drawn to an enlarged scale) are 0.0325 and 0.0333; their ratio is 1.02461. This gives the corrected value of k as 0.7362. The probable change of the value of n with temperature was determined from the average values found by Dr. Brabbée and published in *Gesundheits Ingenieur*, July, 1913. According to these tests the value of n increases 0.00096 per deg. fahr.

The corrected equation of line F_2 is, therefore,

$$h = 0.7362\ V^{1.842} \quad \ldots\ldots (3)$$

In a similar manner, the equation of line F_1, corrected for 70 deg. temperature, is

$$h = 0.5579\ V^{1.838} \quad \ldots\ldots (4)$$

The values of h were calculated for velocities of 1, 2, and 3 ft. per second for both equations; the differences of the respective values were divided by 13 and

TABLE 5. k AND n VALUES

Nominal diameter	Actual diameter	90° S R		90° L R		45°	
		k	n	k	n	k	n
1	1.0425	0.01337	1.977	....	...	....	...
1¼	1.3658	0.01474	1.861	0.00951	1.914	0.00857	1.717
1½	1.6027	0.01371	1.846	0.00822	1.926	0.00940	1.920
2	2.0561	0.01146	1.845	....	...	0.00609	1.788
2½	2.4759	0.01123	1.977	0.00625	1.953	0.00539	1.996
3	3.0566	0.00931	1.803	0.00568	1.914	0.00470	1.939

TABLE 6. k AND n VALUES "NO-LENGTH FITTINGS"

Nominal diameter	Actual diameter	90° S R		90° L R		45°	
		k	n	k	n	k	n
1	1.0425	0.01677	1.851	0.01089	1.915	0.01169	1.891
1½	1.6027	0.01338	1.848	0.00818	1.923	0.00798	1.897
2	2.0561	0.01175	1.843	0.00697	1.922	0.00670	1.896
3	3.0566	0.00954	1.852	0.00537	1.935	0.00450	1.909

plotted, giving the 90° short radius elbow line of Fig. 9 with equation, for one elbow,

$$h = 0.0137\ V^{1.846} \quad \ldots\ldots (5)$$

Having found the friction caused by one short radius elbow, the set-up was changed by substituting 17 long radius 90° elbows for the 17 short radius elbows.

The test was repeated and the data shown in Table 3 and by line F_3, Fig. 7, were secured. The equation of this line corrected for temperature is

$$= 0.6423\ V^{1.860}$$
$$h = 0.6429\ V^{1.856} \quad \ldots\ldots (6)$$

From this equation the values for velocities of 1, 2, and 3 ft. per second were calculated and subtracted from the corresponding values for line F_2. The differences between the respective values, divided by 17, gave the difference between the friction in one 90° short radius elbow and in one 90° long radius elbow.

Subtracting these differences from the corresponding values for a 90° short

radius elbow gave the friction in one 90° long radius elbow. These values are shown in the 90° long radius elbow line of Fig. 9. The equation of this line is

$$h = 0.0082\ V^{1.926} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Having completed this determination the set-up was changed to that shown by Fig. 5 in which the 17 long radius 90° elbows are replaced by 17–45° elbows.

Following the method outlined before, the data shown in Table 4 and by line F_4, Fig. 7, were secured.

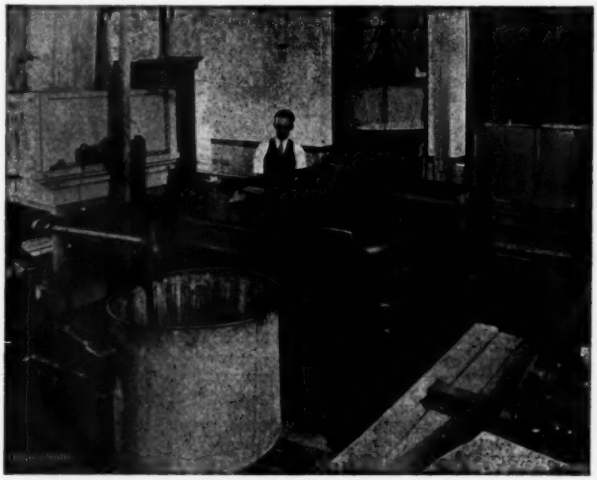

FIG. 6. PHOTOGRAPH OF SET-UP FOR TESTS

The equation of this line, corrected for temperature, is

$$h = 0.6629\ V^{1.862} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Using the same method as that described for the long radius elbows, the line for 45° elbows was determined as shown in Fig. 9. The equation of this line is:

$$h = 0.0094\ V^{1.920} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Similar calculations were made for each pipe size and the k and n values shown in Table 5 were determined. These values are plotted against the actual internal pipe diameter in Fig. 10.

The average lines for n and k each type elbow were drawn and the corresponding equations determined. From the data of Table 5 and from Fig. 10, k seems to be a function of the diameter while n seems to be constant for each type of elbow.

The values of k determined from these lines are shown by the following equations for the respective fittings:

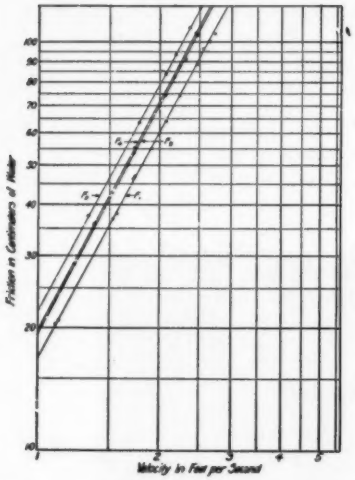

FIG. 7. CHART SHOWING COMPARATIVE [illegible] DATA ON 90° ELBOW TESTS

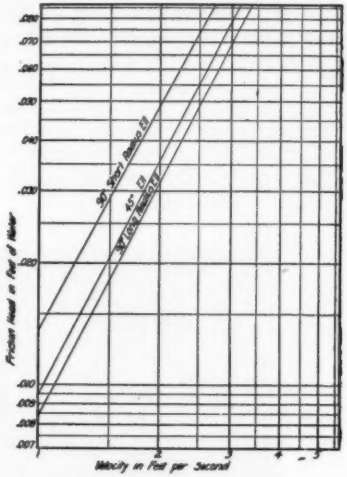

FIG. 9. CHART SHOWING DATA SECURED WITH LONG RADIUS 90° ELBOWS AND WITH 45° ELBOWS

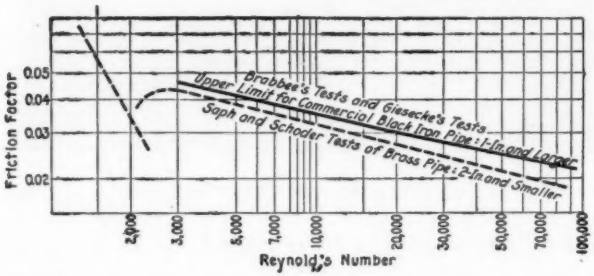

FIG. 8. RELATION OF FRICTION FACTOR TO REYNOLD'S NUMBER

$$\text{One short radius } 90^\circ \text{ elbow} \ldots k = \frac{0.01725}{d^{0.524}} \quad \ldots\ldots\ldots\ldots (10)$$

$$\text{One long radius } 90^\circ \text{ elbow} \ldots k = \frac{0.0114}{d^{0.656}} \quad \ldots\ldots\ldots\ldots (11)$$

$$\text{One } 45^\circ \text{ elbow} \ldots k = \frac{0.0122}{d^{0.586}} \quad \ldots\ldots\ldots\ldots (12)$$

where d is the actual internal diameter in inches.

From the lines of Fig. 10, the n values are 1.85, 1.92, and 1.90, respectively.

The final general equations for the friction head in one elbow are, therefore:

One short radius 90° elbow: $$h = \frac{0.01725\ V^{1.85}}{d^{0.624}} \quad \ldots\ldots (13)$$

One long radius 90° elbow: $$h = \frac{0.0114\ V^{1.92}}{d^{0.656}} \quad \ldots\ldots (14)$$

One 45° elbow: $$h = \frac{0.0122\ V^{1.90}}{d^{0.886}} \quad \ldots\ldots (15)$$

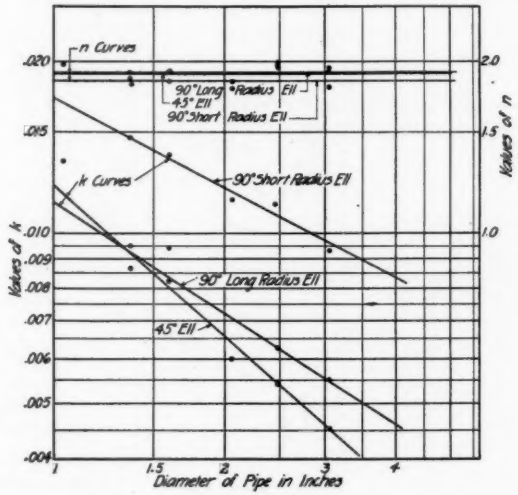

FIG. 10. VALUES FOR k AND n PLOTTED AGAINST ACTUAL INTERNAL PIPE DIAMETER

In order to distinguish properly between the friction in a long radius elbow and that in a short radius elbow, it is necessary to consider the difference in the length of the two fittings. To do this, the writer suggests the adoption of a "no-length fitting" concept.

Referring to Fig. 11, if the distances AB, BC, and CD on the center lines of the pipes are measured, the friction due to pipe on the basis of this length is determined and to this is added the friction of the elbows at B and C, more friction than actually exists is being calculated. To obviate this error, the friction may be calculated in the length of pipe replaced by the elbow and this value subtracted from the friction of one elbow. The result is the friction of the "no-length elbow."

Using the pipe friction values published in University of Texas Bulletin No. 1759, and considering the length of an elbow as twice the distance from the center line intersection to the beginning of the thread, the friction due to that length of pipe was calculated and subtracted from the values of the friction for one elbow

as determined before. The resulting differences are the theoretical values of friction for "no-length elbows."

The method of determining this value is as follows:

From University of Texas Bulletin No. 1759, the friction of 1 ft. of pipe is:

$$h = 0.00685 \frac{V^{1.77}}{d^{1.275}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

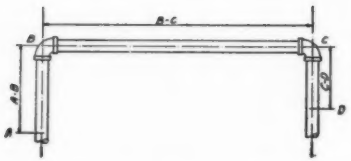

FIG. 11. THE NO-LENGTH FITTING CONCEPT

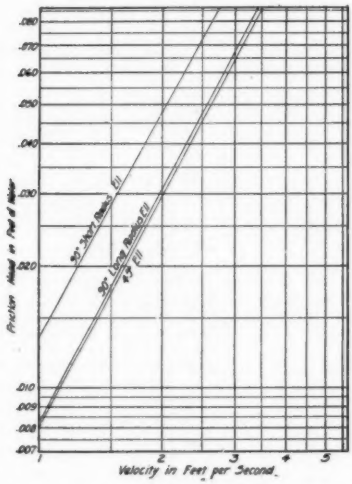

FIG. 12. LINES FROM WHICH EQUATION 17 WERE DETERMINED

TABLE 7. RATIO OF LONG RADIUS 90° AND 45° ELBOWS TO SHORT RADIUS 90° ELBOWS AT VELOCITY OF 1 FT. PER SECOND

Size	Short radius	Long radius	45°
1	1.000	0.657	0.697
1 1/4	1.000	0.634	0.632
1 1/2	1.000	0.621	0.596
2	1.000	0.601	0.545
2 1/2	1.000	0.586	0.509
3	1.000	0.570	0.472

TABLE 8. RATIO OF LONG RADIUS 90° AND 45° "NO-LENGTH ELBOWS" TO SHORT RADIUS 90° "NO-LENGTH ELBOWS" AT VELOCITY OF 1 FT. PER SECOND

Size	Short radius	Long radius	45°
1	1.000	0.649	0.697
1 1/4	1.000	0.627	0.633
1 1/2	1.000	0.614	0.597
2	1.000	0.595	0.545
2 1/2	1.000	0.580	0.510
3	1.000	0.565	0.472

Considering the $1^1/_2$-in. pipe, whose actual diameter was found to be 1.6027 in., the values of the friction were determined for velocities of 1, 2, and 3 ft. per second, and for the length of the elbow, determined as described above. These values were subtracted from the corresponding values of friction for a short radius 90° elbow (Equation 13). The differences are the friction values of the theoretical "no-length elbow." These values plotted against velocity, in Fig. 12, gave a straight line from which the following equation for the friction in one 90° short radius "no-length elbow" was determined:

$$h = 0.01338\, V^{1.848} \quad \ldots\ldots (17)$$

Using the same method, equations were determined for the 90° long radius and

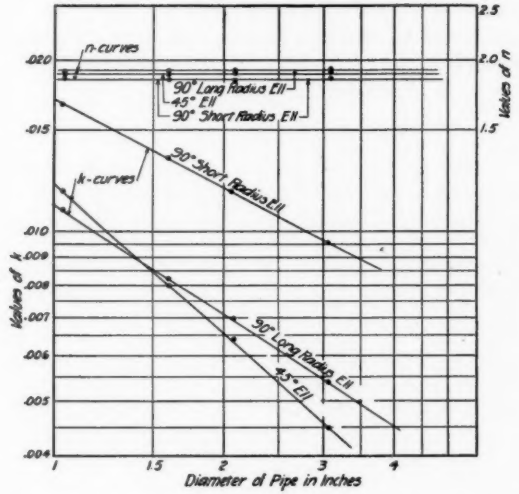

FIG. 13. VALUES OF k AND n IN TABLE 6 GRAPHICALLY SHOWN

the 45° elbows, for the various pipe sizes, and the resulting values of k and n, shown in Table 6, plotted in the series of curves of Fig. 13.

As before, k is a function of the diameter and n is a constant for each type of elbow. The final general equations for the frictions in the theoretical "no-length fittings" are:

One short radius 90° elbow: $h = \dfrac{0.01715}{d^{0.527}}\, V^{1.85} \quad \ldots\ldots (18)$

One long radius 90° elbow: $h = \dfrac{0.01120}{d^{0.657}}\, V^{1.922} \quad \ldots\ldots (19)$

One 45° elbow: $h = \dfrac{0.01215}{d^{0.890}}\, V^{1.896} \quad \ldots\ldots (20)$

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By comparing Equations 13, 14, and 15, the relative friction heads in short radius 90° elbows, long radius 90° elbows, and 45° elbows may be calculated for any desired velocity. This was done for a velocity of 1 ft. per second and the results, expressed in terms of the friction head in short-radius 90° elbows, are shown in Table 7.

Similar calculations were made from Equations 18, 19, and 20 for "no-length elbows," and the results are shown in Table 8.

The experimental work in this investigation was performed by C. P. Reming, Instructor in Architectural Engineering and Assistant in the Engineering Research Division, J. W. Knudson, Graduate Student and Assistant in the Engineering Research Division, L. D. Golden and D. C. Kinney, Seniors in Engineering, and A. B. Awalt, Junior in Education. All deserve much credit for the careful and conscientious manner in which the work was performed.

This investigation will be described in greater detail in a University of Texas bulletin to be issued later.

No. 755

EFFECTIVE TEMPERATURE FOR PERSONS LIGHTLY CLOTHED AND WORKING IN STILL AIR

By F. C. Houghten (Member), W. W. Teague and W. E. Miller (Non-Members)

PITTSBURGH, PA.

THE determination of the relation between temperature, humidity, and air motion and a person's feeling of warmth under various conditions of human clothing and activity has been under way at the Laboratory since the middle of 1922. Several reports[1] giving the results of various phases of the investigation have been published. Earlier reports give the relation between a person's feeling of warmth and temperature and humidity for subjects at rest and stripped to the waist in still air, for subjects at rest and stripped to the waist in various air velocities, and for subjects at rest and normally clothed in still and moving air.

The Laboratory has now completed another phase of the investigation; namely the determination of effective temperatures for persons working in still air while lightly clothed. This study was carried on in the two psychrometric chambers (see Fig. 1), in the Bureau of Mines building in which any atmospheric condition can be obtained and accurately controlled. Complete descriptions of these rooms appear in other Laboratory reports and need not be repeated here.

The investigation of the relation of temperature, humidity, and air motion has been paralleled by a study of the physiological reaction of human beings to various combinations of temperature, humidity, and air motion under similar conditions of activity and dress. This study has been carried on by the Society's Laboratory in cooperation with the U. S. Public Health Service and the U. S. Bureau of Mines. Several reports on this work also appear in the Transactions of the Society for the past three years.

Physiological reactions for the conditions of human activity and environment of subjects reported in this paper were published last January. In keeping with plans followed throughout the two investigations, the same conditions of work and clothing were adhered to in this study. The observers were clothed in shoes, light weight shirt, and trousers. The tests were conducted by having trained

[1] Determining Equal Comfort Lines, F. C. Houghten and C. P. Yagloglou, Mar., 1923. Jour. American Society of Heating and Ventilating Engineers.
Cooling Effect on Human Beings Produced by Various Air Velocities, F. C. Houghten and C. P. Yagloglou, Feb., 1924. Jour. American Society of Heating and Ventilating Engineers.
Effective Temperature with Clothing, C. P. Yagloglou and W. Edw. Miller, Jan., 1925. Jour. American Society of Heating and Ventilating Engineers.

Paper presented at the Semi-Annual Meeting of the American Society of Heating and Ventilating Engineers, Lexington, Ky., May, 1926.

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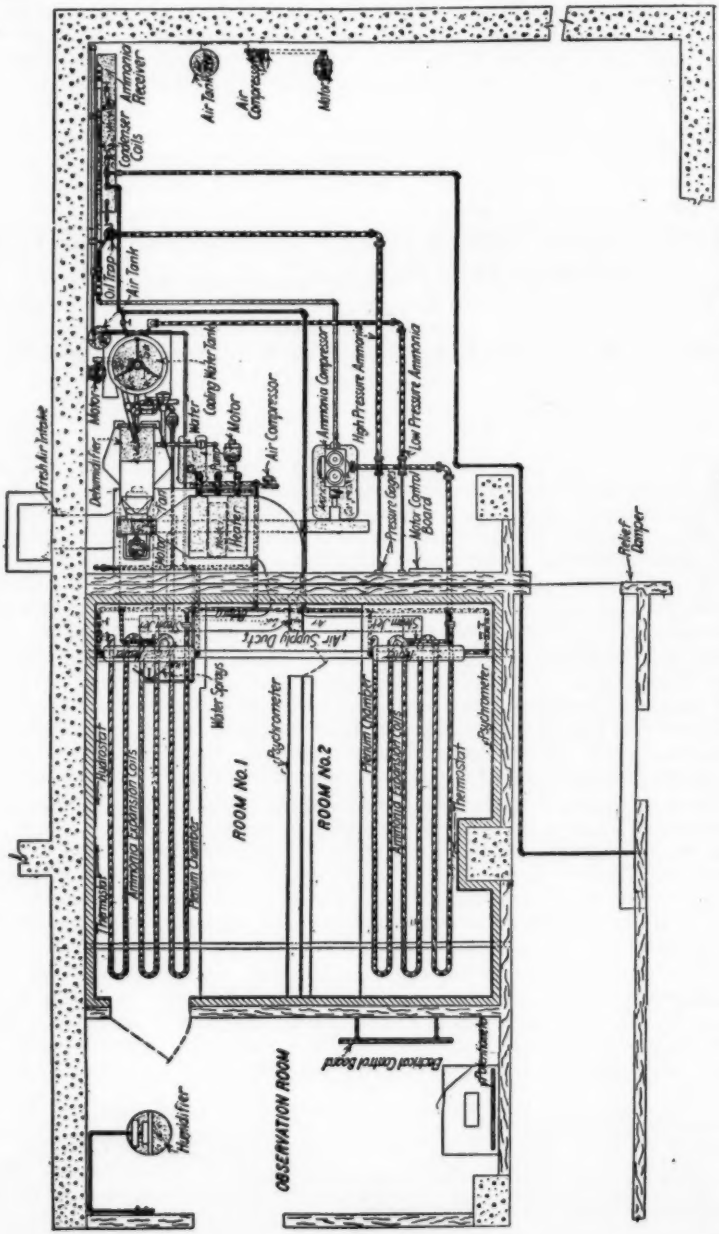

FIG. 1. PLAN OF PSYCHROMETRIC CHAMBERS, ADJOINING ROOMS AND AUXILIARY EQUIPMENT

observers, while working, compare the relative feeling of warmth of two atmospheric conditions, one having a high dry-bulb temperature and low relative humidity and the other having a lower dry-bulb temperature and a higher relative humidity.

In carrying on a test the observer spent five minutes at work raising and lowering a weight through a distance of five feet by means of a rope passing over a pulley, Fig. 2. The weight was adjusted so that a force of 40 lbs. was required

FIG. 2. WORK MACHINE DEVELOPED AT LABORATORY

to raise it. Description of this machine is found in a previous Laboratory publication.[2] After thus working, raising and lowering the weight seventy-five times in five minutes, the observer spends the next five minutes passing back and forth between the two rooms in order to judge their relative feeling of warmth. At the end of this five-minute period the observer again spends five minutes working in the other room. This procedure is continued for two hours during which time the effective temperature of one of the rooms is increased a few degrees from a condition where the observers pronounce it cooler, to a condition where they judge it warmer than the other room, and then again cooled to the original temperature.

[2] Work Tests Conducted in Atmospheres of High Temperatures and Various Humidities in Still and Moving Air, W. J. McConnell, C. P. Yaglogiou, W. E. Miller, and W. B. Fulton, Jan., 1925. JOUR. AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS.

Each time the observers pass from one room to another they independently record their relative feeling of warmth in the two rooms. The two atmospheric conditions which the observers judge to give the same feeling of warmth have the same

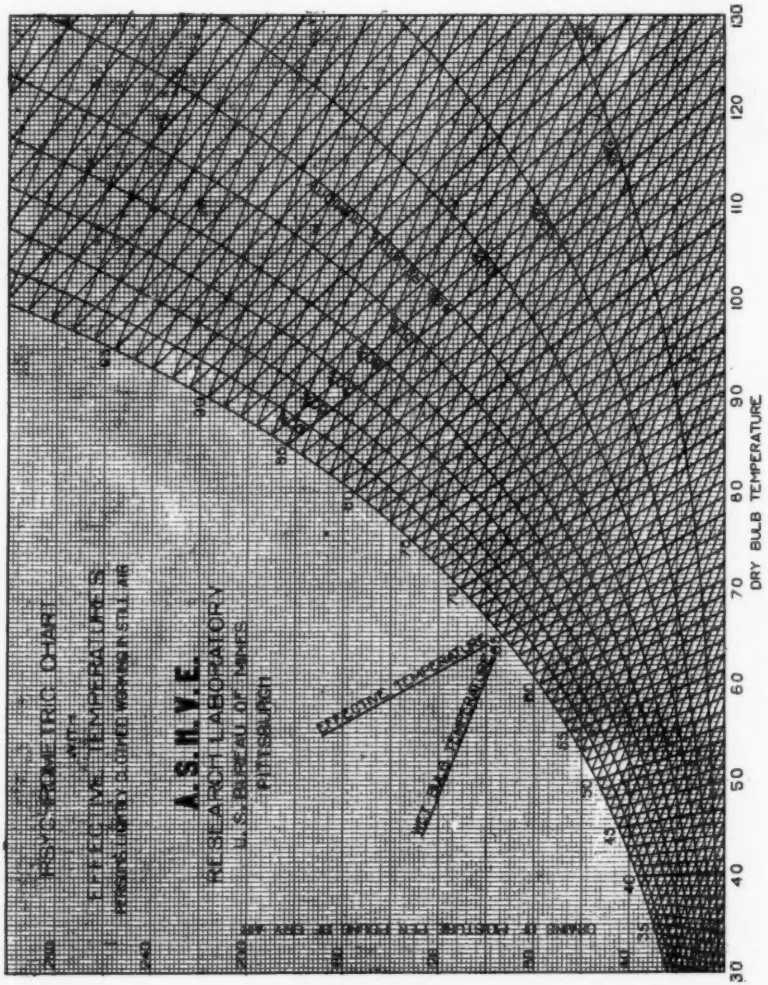

FIG. 3. PSYCHROMETRIC CHART WITH EFFECTIVE TEMPERATURES—PERSONS LIGHTLY CLOTHED WORKING IN STILL AIR

effective temperature for the observers at work, and a line passing through these two points gives an effective temperature line for persons working in still air. Fig. 4 gives the angle between the dry-bulb lines and the experimentally deter-

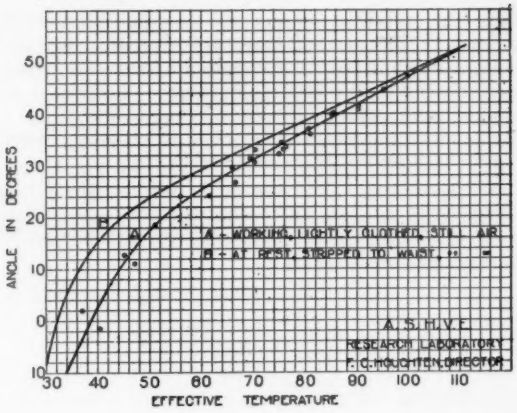

FIG. 4. ANGLE BETWEEN DRY BULB AND EFFECTIVE TEMPERATURES ON CARRIER'S PSYCHROMETRIC CHART

mined effective temperature lines when plotted on the Carrier psychrometric chart. Fig. 3 is the Carrier psychrometric chart with the effective temperature lines determined from the smooth curve drawn through the experimentally determined points in Fig. 4.

The effect of the various conditions of dress, occupation, and air motion on the relation between temperature and humidity for equal feeling of warmth is clearly indicated in the section of the Chart, Fig. 5. The five curves *A* to *E* are all 60

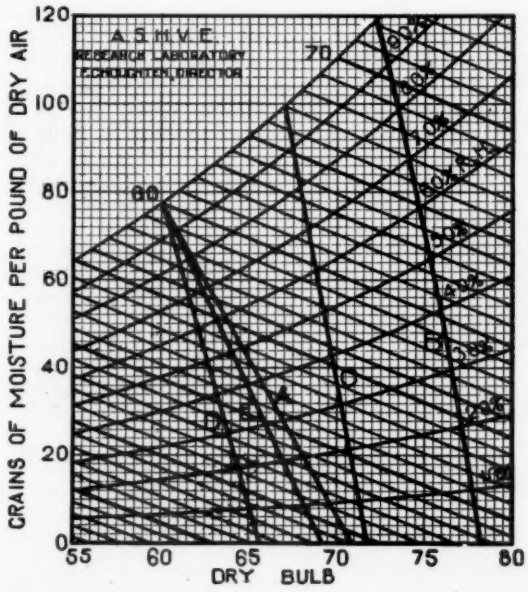

FIG. 5. RELATION BETWEEN EFFECTIVE TEMPERATURES FOR DIFFERENT CONDITIONS OF OCCUPATION, CLOTHING, AND AIR MOVEMENT

deg. fahr. effective temperature lines for the conditions indicated. A person stripped to the waist and at rest will experience the same feeling of warmth in any temperature and humidity indicated by curve *A* if there is no air movement and by curve *B* if there is 300 ft. air velocity. Likewise a person at rest and normally clothed will experience the same feeling of warmth in any condition having the temperature and humidity indicated by curve *D* if there is no air motion and by curve *C* if there is a 300 ft. air velocity.

While working lightly clothed he will feel the same degree of warmth in any temperature and humidity indicated by curve *E*. The equivalent conditions for persons working normally clothed in still and moving air are now being determined and will be reported later.

No. 756

A RATIONAL BASIS FOR VENTILATION

By J. E. Rush,* M.D., Lexington, Ky.

NON-MEMBER

IT is now nearly two decades since, as an undergraduate at the Massachusetts Institute of Technology, I became interested in certain experimental work that was then being conducted on ventilation. It has been my good fortune nearly every year since then to present to classes in Sanitary Engineering, or Public Health, or Hygiene, facts that I thought were pertinent to this subject. It has been necessary for nearly every presentation that I review some of the literature which has accumulated since my lecture of the previous year, and I have attempted to present to my students what might be considered a middle ground and to adopt a conservative attitude; not sponsoring any extremely radical views unless they were accompanied by an overwhelming mass of data. I realized that, as Osler states so well—"The phenomenal strides in every branch of scientific medicine have tended to overload it with detail. To winnow the wheat from the chaff and to prepare it in an easily digested shape for the tender stomachs of the first and second year students taxes the resources of the most capable teacher."[1]

In the preparation of material for classwork I have probably been greatly influenced by my early training and association with Dr. W. T. Sedgwick, than whom I have met none greater in respect to that uncommon attribute, common sense. I can even now recall his own words, as he traced the great argument that took place between Pasteur and Liebig about 1860 relative to whether or not fermentation was a biological or chemical process. He would generalize from this and say that though the opinions appeared to be diametrically opposed, time has shown that "the truth is in the well." It has been my observation many times since then that when two individuals maintained extreme positions on a subject the real truth was frequently intermediate. Due to this training and association more than any other I have been extremely conservative in accepting radical views which have from time to time been presented; relative to the subject of ventilation or any other subject for that matter, at their face value.

In gathering material for lecture work to be used in my classes the following fact has impressed me greatly: the great number of authorities that one may cite as believing in some particular theory, yet frequently they are all giving an opinion based upon only one or two experiments, or only one or two series of experiments.

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* Department of Hygiene and Public Health, University of Kentucky.

[1] Counsels and Ideals, Osler, 2nd Ed., p. 138.

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It would seem that one has a multiplicity of opinions from different sources which of course would vary in their degree of importance with the authority cited until one finds out that the statements are based on the work of one or two persons and therefore they have a limited scientific value. Of course, I realize that it is not possible for everyone who writes a book to do all of the experimental work represented in the book, or even perhaps to do any of it. It probably takes two different types of minds, one the investigating type and the other the collaborating type, but we have a right to expect that those who announce authoritative statements do so correctly. Unfortunately we frequently find in our texts that great errors creep in due to the fact that some of our authors have more or less copied blindly from the work of someone else and seem to lack an appreciation of certain of the fundamental facts involved. In preparing material for presentation one must be constantly on the lookout for errors of this sort. To illustrate what I mean by an example let me cite the following: one of the widely quoted authorities on the problem of ventilation makes the following statement:

> Dr. Chapin, an authority on public health, says that less attention is paid to aseptic surgery and that some of the best surgeons consider it as a negligible factor.[2]

No physician could read such a statement as this without realizing that it is contrary to the basic principles of all scientific surgical precedure of the present time, and knowing Dr. Chapin by reputation and by his work as well as I do, I was interested in finding out what Chapin really had said that could be so misconstrued, and I quote the following from his text, Sources and Modes of Infection:

> Surgeons at first developed aseptic surgery on the theory that air infection was of the highest importance. They have gradually learned to pay less attention to it, until at present some of the best surgeons consider it a negligible factor.[3]

There is a tremendous difference between this statement and the way that it was interpreted. Incidents of this kind crop out frequently and of course do not engender confidence relative to other material by the same author. Authors of scientific books have an exceedingly important task, for relatively few of us have direct access to original sources, therefore these authors who reach great audiences are responsible in no small degree for public opinion and must be extremely careful in their expressions and statements for "Great is truth, and mightly above all things."[4]

Certain General Considerations

Air is man's immediate environment and in relation to an optimum it should be remembered that it serves a most important function in the regulation of the body's temperature and that the oxygen which it furnishes is absolutely necessary for the metabolic processes. It is a fact that there is a very constant chemical composition of the air outdoors over practically the whole of the surface of the earth. On the other hand the composition of indoor air is very variable due chiefly to oxidations; the most important of which, from our point of view, is respiration. Nearly everyone at sometime or other has experienced the oppressiveness of air upon entering a poorly ventilated room and it is usually conceded that the fatigue of the day's work is greatly increased when the ventilation is poor. Most of us have a high regard for the stimulating effect of outdoor life either at the seashore

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[2] Ventilation of School Buildings, McClure, p. 13.
[3] Sources and Modes of Infection, Chapin, 2nd Ed., p. 313.
[4] Apocrypha, 1st Book Esdras, IV, p. 41.

or in the mountains during the summer, and one of the great factors there is fresh air. Everybody realizes that there is a difference between various types of air.

If I am not mistaken Mrs. Ellen Richards frequently referred in our course on Chemical Analysis to the fact that air was the first necessity of life, for while we may live without food for days and without water for hours we can only live without air for a few minutes. It would seem from this that our air supply is of more importance than our water or food supply and from this one would naturally infer that good ventilation when we are in confined quarters would be one of the first rules of hygiene.

The relation of air to man varies in different climates. In the tropics he needs no fire for warmth, no clothing except as modesty may dictate and no work to keep himself warm. On the other hand in the artic zones, fires are necessary for warmth and fuel being scarce, heavy, impervious clothing is used in order to conserve the body heat. The temperate climate furnishes us both of the extremes during its seasonal variations, and it would seem that a highly organized society should, by the fact that its individuals have the ability to harness the forces around them for their best convenience, use heating and cooling and ventilation indoors as circumstances require.

The body may be regarded as a combination of radiator, thermostat and humidifier and usually it produces more heat than is needed whereupon no external heat would be required. Certain observations may be made about apparently healthy individuals at different ages relative to their heat requirements. Less heat is required by young healthy persons, women and by all persons when exercising, while in sedentary life and in old age the heat loss from the body is usually in excess of the heat production and then one feels the need of surrounding the body with an atmosphere that will supply heat or at least not conduct it away rapidly. This shows us too why it has usually been found advantageous to have a study room warm and a gymnasium cool. It must be remembered in this connection that there is a blanket of air enmeshed about the hair and clothing of the individual which serves as an insulator—*the aerial blanket*—to which Professor Sedgwick used to refer and which is present except when a person is exposed to rapidly moving currents of air. Pursuing this thought we see why a thinly clad person or persons who are not well nourished tend to over-heat their dwellings for there is not sufficient heat being produced by their bodies to create a feeling of warmth or it is being removed too rapidly to give them a sense of comfort from their surrounding *aerial blanket*.

Living in a cave or in a hut, primitive man had no problem in ventilation. The pollution of his air supply was negligible and Nature took care of the means whereby he would get more. In many of our attempts to remedy our environment to suit the changes which civilization has brought about, it has been necessary that we keep constantly in mind the removal of the end products of our own existence and bring in fresh material to replace that which has been used. The living organism has been aptly compared to a flame or a whirlpool whose form is relatively constant but with an income and a definite outgo; this latter represents the end products of our existence and its ultimate disposal is frequently a problem of great magnitude from the points of view of health, comfort and decency. In this connection I quote as follows:

> From the earliest times it was evident that although an adult partook of a great deal of food, he did not gain in weight. Hippocrates believed this to be due to a constant loss of insensible perspiration and to the elimination of heat, which he conceived to be a fine form of matter. Galen, 600 years later than Hippocrates, was no further advanced

in this conception of nutrition. For 1300 years after Galen intellectual progress lay dormant under the spell of the Dark Ages.

One of the first inquirers of the Renaissance, the brilliant Paracelus, explained the phenomenon of nutrition as being under the supervision of an archeus, a spirit which dwelt in the stomach and separated the food into the good and bad, the good being used by the organs of the body, and the bad eliminated.[5]

As primitive man advanced he built dwellings for himself and provided inlets for sunshine and air in the form of windows, and when he became a more social individual, meeting places were built and it was found, time and again, that sufficient air did not find its way fortuituously in by the windows and through the walls to supply great gatherings of people. Civilized man dealt with the problem of ventilation as he has done with the problem of water supply and other problems which affect groups of people, namely, he provided means whereby increased amounts of the desired material should be brought in under controlled conditions, rather than depending upon chance. These were changed to suit the new circumstances, *i. e.*, water was filtered and softened; air was cleaned and warmed.

With our ever increasing artificialities of life there is a definite need for us to have our science advanced in order to take care of, what from Nature's point of view, must be an interference with natural law. The control of many of our disease conditions was a relatively simple matter before we grouped ourselves together in towns and cities and before intercourse was simplified by the railroad and automobile. All of these conditions which constitute such a wide departure from primitive man's life out of doors must be met by altering our surroundings to make our artificial modes of living possible. The control of typhoid fever, the control of most of the communicable diseases were simple until we began getting so close together that we polluted the environment of our neighbor, either directly or through some medium, such as air or water. In order that such artificial extremes of existence may obtain, steps must be taken to meet the new conditions as they arise; if it is possible for us to so alter conditions to off-set the changed circumstances, such as inoculation for small pox, then the toll from this is controlled, but if our scientific safeguards do not keep pace with our changing civilization, catastrophies like the recent influenza pandemic are greatly increased.

As stated the living animal must take food from its surroundings and must return end products to its environment—it selects a variety of organic substances and small amounts of mineral salts and these constitute its food; it also takes from its environment a supply of oxygen which is not usually reckoned as a food. The term *food* is usually reserved for material which may serve a constructive purpose in the organism or at least has the capacity for storage within the cell. The function of oxygen is not to promote constructive processes but to release energy and therefore it concerns itself with the process of destruction in which the stored materials in the cell are used. The process whereby oxygen unites with substances in the cell eventuating in oxidized products to replace the relatively complex food materials rich in potential energy is usually called *respiration*. Respiration is frequently used as a synonym for breathing though the chemical sense in which it is here used is more desirable. The similarity between respiration and combustion has been frequently noted and is a very good one for demonstration, for while they are not identical the initial and final conditions are quite alike for both. Respiration has been said to be a process in the course of which compounds are decomposed and potential energy is made available. As in most other decompositions, the larger amount of the energy appears as heat; a much smaller part manifesting itself in other ways.

[5] The Fundamental Basis of Nutrition, Lusk, 2nd Ed., pp. 1–2.

The history of science bristles with individual conclusions that are opposed to the current teachings—some times they have stood the test of time, but more frequently they have failed to survive because they were erroneous. It is extremely dangerous unless one knows every field at which a subject may touch others to generalize from too few data or from data which are not complete and checked carefully by other investigators. For years the great mass of the people saw a connection between swamps and malaria, and when the role of the mosquito was worked out this *old foggy idea* about the proximity of swamps was laughed to scorn, but when we have added knowledge and know that the mosquito does not travel far from his normal habitat, reason for this observation on the part of the laity and its *extreme* importance was evident. Again it must be remembered that a great mass of the people were cognizant of the fact that cow-pox immunized against small pox, and when this was worked out statistically by Jenner the result was perfectly clear. Before that time, however, (1796) it was looked upon as a grandmother's idea. A great mass of individuals in a republic may move slowly but their advance usually denotes steady progress—a single individual or a handful of individuals may make great errors, which if accepted at their face value before there is conclusive evidence may do untold harm. Oliver Wendell Holmes, whom all know as a poet but who was of much greater service to the world as a physician has been often my guide. There appears in Morse's "Life and Letters," Holmes' own words:

> I have more fully learned at least three principles since I have been in Paris; not to take authority when I can have facts; not to guess when I can know; not to think a man must take physic because he is sick:

and again,

> My aim has been to qualify myself—not for a mere scholar, for a follower after other men's opinions, for a dependent on their authority, but for the character of a man who has seen and therefore knows; who has arrived at his own conclusions.[6]

But as Osler so truly remarks:

> Only by keeping the mind plastic and receptive does the student escape perdition.[7]

Again in reference to the biological sciences Osler says:

> Biology touches the problems of life at every point, and may claim, as no other science, completeness of view and a comprehensiveness which pertains to it alone. To all whose daily work lies in her manifestations the value of a deep insight into her relations cannot be overestimated. The study of biology trains the mind in accurate methods of observation and correct methods of reasoning and gives to a man clearer points of view, and an attitude of mind more serviceable in the working-day world than that given by other sciences or even by the humanities.[8]

In our constant pursuit of scientific truths we are reminded of Milton from whom I quote:

> Who ever knew truth put to the worse, in a free and open encounter?[9]

and later,

> Truth is as impossible to be soiled by any outward touch as the sunbeam.[10]

Let us feel with Francis Bacon that,

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[6] Epoch-Making Contributions to Medicine, Surgery and the Allied Sciences, Camac, p. 394.
[7] Counsels and Ideals, Osler, 2nd Ed., p. 83.
[8] Counsels and Ideals, Osler, 2nd Ed., p. 58.
[9] Areopagitica, Milton.
[10] The Doctrine and Discipline of Divorce, Milton.

XUM

No pleasure is comparable to the standing upon the vantage-ground of truth,[11]

while as Thomas Jefferson said,

Error of opinion may be tolerated where reason is left free to combat it.[12]

Though practically every discussion on ventilation contains references to the history of ventilation, I hope that I will be pardoned if I make statements relative to it, for as Libby says in his Introduction to the History of Science, in relation to the value of having some background for the subject under discussion:

It (The History of Science) presents science as the constant pursuit of truth rather than the formulation of truth long since revealed; it shows science as progressive rather than fixed, dynamic rather than static, a growth to which each may contribute. It does not paralyze the self-activity of youth by the record of an infallible past.[13]

It is with these ideas in mind that I approach the subject of my paper, namely, A Rational Basis for Ventilation.

Historical

The last part of the 17th century and the first part of the 18th century was a time when the experimental method was coming into more general use. Up to this time the phlogiston theory of chemistry was the predominating principle and this, the 18th century so far as chemistry is concerned, may be looked upon as a Scientific Renaissance.

Boyle, Hooke, Lower, Mayow, Priestly and others had completed a good deal of experimental work on the atmosphere, some of which indicated that if small animals were placed in air-tight compartments they soon died. They also found that when one animal died and they then introduced a second animal into the same jar without changing the air in the jar that the second animal died within a shorter time than the first and their conclusions were that the air in the jar was no longer able to support life. The same experiment was repeated substituting for the animal a lighted candle and the results may be summarized by saying that light and life were likewise extinguished. They then experimented to see if the candle and the mouse caused the same type of changes in the air and it was found that mice would not live in air in which candles could not burn, so evidently there was something similar in the burning of a candle and the breathing of an animal.

Black says in 1757:

I have convinced myself that the change produced in healthful air by the act of respiration consists principally, if not entirely, in converting a part of it into fixed air (now called carbon dioxide), because I found that in breathing by means of a tube into water of lime or into a solution of caustic alkali, I precipitated the lime and caused the alkali to lose its causticity.[14]

While Black was working in Scotland and Bergmann in Sweden, Cavendish was similarily engaged in England and reported in 1766 his discovery of a new kind of gas which he called *inflammable air* because it took fire whenever flame was applied to it. He had obtained this gas by the treatment of different metals with sulphuric acid very much as Black had obtained *fixed air* by treating limestone with acid. There was quite a difference between these two types of *airs* for *inflammable air* was lighter than ordinary air, not heavier, as was *fixed air* and was readily

[11] Essay of Truth, Francis Bacon.
[12] Inaugural Address of Thomas Jefferson, Thomas Jefferson.
[13] History of Science, Libby, Preface, p. V.
[14] Physiological Chemistry, Matthews, 3rd Ed., p. 270.

burned. It resembled *fixed air* in that animals died when placed in it and it had another peculiar property, namely that of forming with air an explosive mixture. The new gas was now named hydrogen.

On August 1, 1774, Joseph Priestly discovered *dephlogisticated air* now called oxygen, by decomposing a reddish powder obtained from mercury. He collected and examined the gas and showed that candles and coal burned in it with much more energy than they did in ordinary air. On inhaling it he said he experienced a sense of exhilaration. He came to believe that the supporter of combustion and the supporter of life (respiration) were identical and this idea caused him to experiment with animals in the gas that he had isolated. Before the end of the century the investigations of Priestly, Scheele and others inspired Dr. Thomas Beddoes to found the Pneumatic Institution in one of the suburbs of Bristol and to treat patients by means of the newly discovered airs. Beddoes had associated with him Davy who for months experimented with nitrous oxide because of the fact that it supported combustion like pure oxygen though by others it had been suspected of being a *principle of contagion*. Davy ventured to inhale the gas and its value as an anaesthetic slowly came to be realized.

The Swedish investigator, Scheele, had almost simultaneously (1775) independently discovered the same gas (oxygen) and he thought that the atmosphere was composed of at least two gases. Later Scheele proved that carbonic acid resulted from both combustion and respiration. Priestly's book, Experiments and Observations on the Different Kinds of Air (1774 et. seq.), gives some indication of how little is known concerning the chemistry of gases at that time. The composition of the atmosphere was not accurately known; marsh gas, carbon dioxide, oxygen, nitrogen and hydrogen were thought of as *kinds* of air. Priestly, as above stated, called this gas *dephlogisticated air* but it is now called by the name given to it by Lavoisier, namely, oxygen. The term oxidation which literally means a scuring is from the Greek *oxys*, meaning acid, and includes in chemistry not only processes which involve the transfer of oxygen but signify any process which results in the increase of the number of positive valences of a compound or element, whether produced by oxygen or some other agent. Priestly's experiment with this gas which he produced showed that it supported combustion better than ordinary air and he also showed that this gas had the ability to change dark venous blood into red arterial blood which was similar to the change that was known to take place in the lungs.

Lavoisier may be looked upon as the chief founder of modern chemistry and most certainly as the reformer of chemical nomenclature. In 1772 he discovered that when he burned sulphur there was a gain in weight and five years later concluded that air consists of two gases, one capable of absorption by burning bodies, the other incapable of supporting combustion. He called the first oxygen. After his studies the atmosphere was no longer regarded as mysterious as it was known to consist of oxygen and nitrogen, and to contain aqueous vapor, carbonic acid and some ammonia. He went farther and found that an animal or man, like a burning piece of wood, absorbed oxygen and eliminated carbon dioxide. He discovered that the process of heat in man was one due to oxidation, that the prevailing idea that particles of air entered the salt and sulphur containing blood and there caused fermentation was untrue. Lavoisier measured the heat given off by a guinea pig by noting the quantity of ice melted by the animal when placed in a hollow block of ice and he measured the gases given off by the animal in order to determine whether the heat produced could be accounted for by the oxidation that was in progress. A true conception of the nutritive process could only be

formulated when a knowledge of the existence of the various gases was revealed. It was Lavoisier who first showed that when an organic substance burned, the products of combustion were equal to the sum of the original substance and oxygen. Oxygen had but recently been discovered by Priestly. Lavoisier burned plants and found that carbon dioxide and water resulted, therefore he concluded that plants contained carbon and hydrogen and on further analytical work he decided that animals contained nitrogen in addition. This was really the first accurate analysis of organic material.

The progress of science is a history of great discoveries of facts which become established, and of destruction of theories which are temporary mental conclusions shown later to be untenable. Nor can a master mind like that of Lavoisier escape the application of this universal law. He showed that animal heat was due to a process of oxidation but he believed that the heat produced was caused by the union of oxygen with carbon and with hydrogen in the lungs. It was not till sixty years after his death that it was fully realized that the heat production was due to the oxidation of protein, fat and carbohydrate within the different organs of the body.[15]

The continuation of this experimental work by Lavoisier and his observations thereon may be summed up in the following statement:

I have been forced to two conclusions equally probable and between which my experiments do not permit me to decide. Either the portion of air eminently respirable (oxygen) contained in atmospheric air is converted into (carbon dioxide) fixed air in passing through the lungs; or it makes an exchange in this organ, on the one hand the eminently respirable air is absorbed, and on the other hand the lungs return it for a portion of carbonic acid almost equal to it in volume.[16]

Later in his Memoirs to the Royal Academy, in 1777 he says:

I have shown that the pure air after having entered the lungs comes out in the state of fixed air (carbonic acid). The pure air in passing the lungs undergoes a decomposition analogous to that which takes place in the combustion of coal. But in the combustion of coal there is a disengagement of heat (materie de feu), of which there should be a similar disengagement in the lungs in the interval of inspiration and expiration and it is this heat, without a doubt, which distributed by the blood throughout the animal economy gives rise to the constant temperature of about 32.5 deg. R. This idea appears perhaps hazardous at first glance, but before rejecting or condemning it, I ask that it be considered that it is founded on two constant and incontestable facts: namely, on the decomposition of air in the lungs, and on the liberation of matter of fire (heat) which accompanies all decompositon of pure air, that is to say all passage of pure air to the state of fixed air.[17]

As further proof of this hypothesis he points to the fact that those animals which are warmest, such as the birds, produce the most carbon dioxide in a given time in proportion to their weight.

In carrying out his experimental work he claimed that animal heat was due to decompositions in the body and he attempted to measure the amount of heat produced by an animal by using the ice calorimeter which had been introduced by Black. Lavoisier and Laplace were concerned with much the same type of experimental work and though their investigations were interrupted by the French Revolution and the death of Lavoisier on the guillotine in 1794 he had summed up his work in these words:

Respiration is only a slow combustion of carbon and hydrogen, which is similar in all respects to that which takes place in a lamp or lighted candle; and from this point of view the animals which respire are truly combustible bodies which burn and consume themselves. In respiration, as in combustion, it is the air which furnished oxygen and

[15] The Basis of Nutrition, Lusk, 2nd Ed., pp. 3–4.
[16] Physiological Chemistry, Matthews, 3rd Ed., p. 271.
[17] Physiological Chemistry Matthews, 3rd Ed. p. 271.

heat but since in respiration it is the substance of the animal itself, it is the blood which furnished the combustible, if the animals do not habitually repair by their aliment that lost by respiration, the oil would be lacking just as in a lamp; the animal would perish like a lamp extinguished when it lacks nourishment. The proof of this indentity of respiration and combustion is deducted immediately from experiment.[18]

Lavoisier had concluded that an excess of carbon dioxide or a lack of oxygen was the cause of asphyxiation in badly ventilated places, while Claude-Bernard in 1857 explained the view that the injurious effects were due to the fact that carbon dioxide interferred with the absorption of oxygen, even though LeBlanc had in 1842 demonstrated that an animal could breathe air containing 30 per cent of carbon dioxide for nearly an hour and recover when it was transferred to a normal atmosphere.

It was Max von Pettenkofer in 1863 who first expressed the conclusion that under ordinary conditions the increase of carbon dioxide was not any more responsible than the decrease of oxygen for the symptoms produced by bad air, because the actual quantitative changes in these constituents recorded in a poorly ventilated room were far below the level at which harmful effects were noted in laboratory experiments. Pettenkofer's idea was, however, that bad air was due to the presence of organic substances excreted from the body. Since he had no direct way of estimating the *morbific substances* or *anthropotoxin* to which he attributed the effects of a vitiated atmosphere he used the concentration of carbon dioxide and this standard was practically universally accepted and translated into the following terms. If the average individual produces 0.6 cu. ft. of carbon dioxide per hour in respiration, and a normal outdoor air contains 0.0003 part of carbon dioxide, if it is assumed that double this normal amount of carbon dioxide is taken as the upper limit of concentration and use this upper limit as the greatest concentration of the hypothetical poison allowable it is easy from this to compute the amount of outside air which should be brought into a room to keep the concentration of carbon dioxide below 0.0006 parts. This may be calculated from the following formula

$$\frac{0.6}{0.0006 - 0.0003} = X$$

which gives 2000 cu. ft. per hour or about 30 cu. ft. per min. per person.

Following along the line of LeBlanc's experimental work Hermanns in 1883 reported that the untoward effects of air in occupied rooms was due to excessive temperature and humidity and thus the so-called *thermal* theory of ventilation which has been supported by Flugge and others came into being in 1905. The work of Flugge is possibly one of the most important pieces of rather early experimentation in ventilation and in his research he showed that a person placed in an air-tight cabinet in which the temperature might be raised to 75 deg. fahr. and the relative humidity to 89 per cent while the carbon dioxide content was increased to 1.5 per cent, became exceedingly uncomfortable. The further and more important fact that people outside the experimental chamber breathing the air from within the chamber through a mouthpiece felt no discomfort but that one entering the chamber became uncomfortable was also established. This type of experiment was repeated and it was shown that even though the man inside the chamber was allowed to breathe air from outside of the chamber through a mouthpiece, his discomfort was not decreased. It was shown, however, that by decreasing the temperature of the air within the chamber or by the movement

[18] Physiological Chemistry, Matthews, 3rd Ed., p. 274.

of the original air in the chamber, by means of a fan, the subject felt greatly relieved even though no new air was admitted to the chamber. This work was repeated many times but notably by Dr. Leonard Hill and his colleagues in 1913 and the explanation of the uncomfortable feeling which one experiences in poorly ventilated rooms is explained on a physiological basis as follows:

The *aerial blanket* which always surrounds us except when we are in contact with rather rapidly moving currents of air is warmed up to the body temperature and is saturated with moisture so that the cooling of the body by radiation, convection, or by evaporation becomes well nigh impossible. This in turn leads to sweating and flushing of the skin with a consequent increase in skin temperature and the blood thus sent to the skin remains there and stagnates and thus produces a lack of circulation to the internal organs. Feelings of discomfort and fatigue result if this condition is allowed to persist but if the *aerial blanket* is removed, as can be accomplished by setting the air in motion, the normal processes of the body are not interferred with and the subject again becomes comfortable. It will be seen from these experiments that the type of air which surrounds the body and its physical composition rather than the type of air which we breathe or its chemical composition is being emphasized at present as having the most important effect upon the problem of ventilation.

The Chicago Ventilation Commission which reported in 1914 emphasized the fact that carbon dioxide in the concentration in which it is usually met in expired air is not harmful; that 68 deg. fahr. is the proper maximum temperature for artificial heat in living rooms and that such air should have a proper relative humidity. It also emphasized that from the point of view of healthfulness relative humidity is one of the important factors in ventilation and that it is impossible to designate all of the harmful factors associated with expired air.

Perhaps in outlining the problem there is no better way in which it can be attacked than in quoting some of the authoritative statements, which one is able to find relative to the effect of different types of atmospheres. Parkes and Kenwood define ventilation as follows: "Ventilation is a term which has a somewhat extensive meaning. Generally it may be said to imply the removal and dispersion of foreign gases or suspended matters which have accumulated in the atmosphere as the result of the vitiating processes already described."[19] Natural ventilation as applied to circumscribed localities may be said to differ with (1) diffusion of gases, (2) the action of the winds, (3) the difference in weight of masses of air of unequal temperature.

In this connection note the statement of D. D. Kimball, one of the members of the New York Ventilation Committee, which appears in Vol. 18 for 1912 of THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS.

> This brings us face to face with the fact that it may well be doubted whether it is known today what are the essentials of ventilation; indeed, it may be safely stated that they are not known. Many are the supposed authorities and statements supporting our present ventilation standards, but actually little, almost no basic conclusive data or authorities are available which are acceptable to the biologist, physician or inquiring engineer. It is high time that this problem of promoting the health of the people by means of ventilation was given the benefit of a scientific and unquestionable basis. The spirit of investigation has taken hold of this problem in this country and abroad in a most encouraging way and to an extent but little appreciated by the average ventilating engineer. The physician and the biologist, as well as the engineer, are actively at work in a serious attempt to solve the problem.[20]

[19] Hygiene and Public Health, Parkes and Kenwood, 6th Ed., p. 200.
[20] TRANSACTIONS A.S.H. & V.E., D.D. Kimball, Vol. 18, 1912, p. 135.

I am rather of the opinion that there is much in this statement made only a little over 10 years ago which is true today. Let me quote from the same volume some statements by Prof. C.-E. A. Winslow:

All along the line civilized man is improving upon Nature and there can be no question that, when we determine just what quantity of air we need, it will be feasible to supply that air to the occupants of a room by use of mechanical devices. On the other hand, it is quite impossible to control the condition of the air in an inclosed space in cold weather by opening windows, for, if those at a distance from the windows feel comfortable, those near the windows must inevitably be exposed to unendurable drafts. The trouble has not been with ventilation *per se*. Neither in my judgment has it rested mainly with the engineer but with the sanitarian who has failed to tell the engineer what to do and with the janitor who has failed to operate the plant after it is installed.

Up to two years ago the designing engineer was told that all he had to do in order to ventilate a school was to supply 30 cu. ft. of air per min. Nothing was said in particular, to him about the quality of the air. Even today, the sanitarian is unable to give a full or satisfactory answer to the question as to what sort of air the engineer should furnish. We do not know that a temperature of over 70 deg. is distinctly harmful. We know that too much humidity is bad and we are reasonably sure that too little humidity is also bad. Just how much or how little we cannot say. These are all points which can be solved, however, and their solution is one of the most interesting problems of the next ten years. The fundamental aspects of water supply, sewage disposal and garbage disposal have been practically worked out. The live question in sanitation at present is this question of air supply.[21]

It would seem that a recapitulation of the theories of ventilation which have been discussed and which have taken us up to a few years ago might be considered at this point. We have outlined the early work in which it was believed that an actual decrease in the oxygen content was responsible for the untoward effects observed in hermetically sealed chambers. This was followed by the theory that it was not the decrease in oxygen but rather the increase in end products, first, carbon dioxide; later a subtle poison that was produced on breathing which caused the difficulty. These theories one after another have been given up though to the persons who propounded them and even to a great number of people who were interested in the subject of ventilation they were at the time acceptable.

Later, we have seen the rise of the so-called *thermal theory* which in effect entirely disregards the air we breathe and emphasizes the air which surrounds the body. This theory is acceptable to many persons but it neglects to take into account the character of the air which is actually used by our bodies and that there are variations in the problem depending upon local circumstances and conditions of living and the like.

The experimental work in the calorimeter in which the subject has been relieved simply by putting the air in motion and has not been relieved by breathing outside air and also that the air of the calorimeter when breathed by persons outside of it produced no untoward effects is taken as proof positive that the air we breathe is of no significance. At this point I should like to point out that those experiments have been of extremely short duration, that we recognize such gross conditions as atrophic rhinitis as due frequently to improperly conditioned air breathed over a long period of time and which would not obtain in this experiment. Other changes, perhaps, less easily diagnosed and even more far reaching from the point of view of our health may entirely fail to establish their etiological relationship to improperly conditioned air because the physiologists and particularly the physiological chemists have not yet been particularly active in the necessary determination. We are at the present time in the problem of ventilation in about

[21] Transactions A.S.H. & V.E., Prof. C.-E. A. Winslow, Vol. 18, 1912, p. 150.

the same position as was Oliver Wendell Holmes before the days of bacteriology when he was dependent upon a statistical approach for a solution of his problem. The statistical method is fraught with danger and this problem is much more complicated than is the problem of puerperal septicemia.

The importance of proper ventilation irrespective of how it may be obtained or what the basic factors that are concerned is recognized by all. The experiences in the Black Hole of Calcutta and on the steamer, Londonderry, are too well known to be repeated and the effect which a poorly ventilated room has upon the occupant is also well recognized. The symptoms of dullness, headache, sleepiness, fainting, nausea and the like have been experienced by most of us. We have expressed the opinion that good ventilation is an asset. That poor ventilation may have a deleterious effect upon the individual as has already been experimentally shown by a decrease in the appetite and a disinclination to activity and a decrease of work accomplished compared with the conditions when the individuals have fresh air. There is also certain evidence to show that offensive odors are rather deleterious to health.

The effects of good air and good ventilation are about as commonly known to all of us as are the effects in poorly ventilated rooms. Medical men have always emphasized the great advantage of good air in the treatment of all types of diseases and particularly for the treatment of diseases of the respiratory tract. The experience of Trudeau at Saranac Lake, which has been multiplied many times in this country and abroad show not only the great advantage of fresh air in the treatment of tuberculosis but that there is definite indication that fresh air is one of the most valuable factors in the prolongation of life. It must be remembered, however, that in the *fresh air* treatment of disease there are probably many other factors operating and an analysis of these factors is extremely difficult.

Reilly in his book on Headache says:

> Foul air produces headache, but here is often a question whether the headache is not due to a nasal obstruction, made worse by the stuffy atmosphere rather than the gases inhaled. This sort of headache is common on awakening in the morning, in those sleeping in a closed room. It is relieved by getting out in the air.[22]

Overton and Denno in regard to indoor air says:

> While human beings are adapted to live healthful lives amid the changes which naturally take place in the outdoor air, they are readily affected by some of the conditions which develop in the air of a closed room as the result of breathing and of fires. Air which has been inhaled or made foul by breathing and combustion produces bad effects upon the body both immediately and also remotely. The immediate effects are dullness, oppressive breathing, headache and general discomfort and are almost exactly similar to those produced by warm air at a temperature near that of the body.
>
> The remote effects of foul air are a general lowering of bodily vigor and a vague weakness and lack of tone. These effects may best be appreciated by contrasting them with the tonic effects of the fresh air in the outdoor treatment of tuberculosis.[23]

Relative to the tonic effect of fresh air Barker and Sprunt in their text book on the Degenerative Diseases say the following:

> Fresh air is tonic and invigorating; vitiated air is depressing and enervating. The harmful effects of a vitiated atmosphere upon human beings may be divided into two general groups, the acute and the chronic. Among the acute effects are lassitude, headache, vertigo, nausea, collapse, and in extreme cases, even death. Much more important from the hygienic standpoint are the more common effects of chronic exposure to contaminated air upon the human constitution. Among them we may

[22] Headache, Reilly, p. 49.
[23] The Health Officer, Overton-Denno, pp. 468–469.

mention anaemia, depressed vitality, digestive disturbances, nutritional disturbance and lowered resistance to infection, with the ordinary pyogenic, or pus-forming bacteria, the tubercle bacillus, the pneumococcus, and the various organisms that are responsible for the ordinary respiratory infections that are so common in winter. Usually when bad ventilation exists there are other unfavorable influences also at work, so that it is difficult to evaluate precisely the harmfulness of anyone of them. Considerable evidence has been adduced however, to show that badly ventilated quarters have a distinctiv deleterious effect upon men and lower animals.[24]

In this connection I should like to point out that much of the work that has been done relative to observations in experimental chambers is not directly applicable to the problem of ventilation as we ordinarily understand it, from the point of view of a place in which people assemble. Experimental work which has been conducted in calorimeters is of course, extremely important from the point of view of certain types of determinations. However, many factors come into play in factories, schoolrooms and living rooms which can hardly be duplicated. In order to more fully appreciate the attitude which is taken toward the importance of this subject perhaps it would be well to quote from one of our authorities in this field:

> It is important to emphasize of all in any consideration of this subject that nothing in the recent work tends in the least to minimize the incontrovertible fact that bad ventilation does, in fact, exert the most profound effect upon human health and comfort. In a crowded, ill-ventilated room we experience a feeling of dullness, sleepiness and under more extreme conditions faintness and nausea; while there are several classic instances in which such conditions of the atmosphere have become so extreme as to result fatally.[25]

It would seem that the object of ventilation of occupied rooms is to maintain the air in a condition in which it approximates that of outdoor air on a pleasant, temperate day of summer. In the addition of air or its removal from rooms it should be our attempt not to create a draft. To define the common term draft is apparently a rather difficult thing, but perhaps a working definition may be a current of air which removes one part of the *aerial blanket* in such a way that the heat is removed from the body more rapidly than it is generated. If this took place over the whole surface of the body we would not consider it a draft because of the fact that the heat regulating mechanism of the body would then come into operation and would cause a readjustment of the circulation.

While we realize that the evil effects of placing many persons in a confined space does not come from a diminution in oxygen or an increase in carbon dioxide, nor from the chemical vitiation of the air nor the presence of a volatile organic poison, there is considerable evidence to show that increase in temperature and humidity and a lack of movement of the air are the important factors. Increase in the surrounding temperature makes it more difficult for the body to get rid of its heat by radiation and conduction and increase in humidity increases the difficulty of cooling effects by the evaporation of perspiration and the result is an elevation of bodily temperature, a decreased vaso-motor tone, the gorging of the skin with blood, and the symptoms that have already been described. In order to avoid the discomforting and debilitating effects on the body due to lack of ventilation it would seem that we should consider ourselves well within our rights to attempt to control all the factors which we have a right to expect would obtain in an air supply, which would give us optimum conditions, that is, the air should be clean, free from dust or excessive amounts of bacteria—it should be free from objectionable odors and should have a proper temperature, humidity and an agreeable amount of movement. To approximate those conditions of chemical

[24] The Laws of Health, Winslow and Williamson, pp. 89–90.
[25] Fresh Air and Ventilation, Prof. C.-E. A. Winslow, Mar. 1926, p. 35.

composition which we have found can be borne by living organisms for a short period of time should not be our aim. It would seem too that there must be something that could approximate an optimum for temperature, humidity, and air movement. If we can determine all of these factors and that does not seem an impossible task, then we should be able to reproduce them, for control of man's environment to best suit himself is one of the earmarks of a high state of civilization.

Perhaps it would be well to review changes which take place in the air of an unventilated room.

Composition of the Air and Changes on Respiration and Combustion

The following table gives the composition of outdoor air:

Nitrogen	78.09
Oxygen	20.94*
Argon	0.94
Carbon dioxide	0.03
Helium, krypton, neon, xenon, hydrogen, hydrogen peroxide, ammonia, nitric and nitrous acids	traces

* 0.01 may be in the form of ozone.

Water vapor varies to such a great extent that it is usually omitted from statements relative to the ordinary composition of the atmosphere. Nitrogen and argon are inert and we would therefore expect that they would show a relative constancy in their concentration, and it might be thought with some reason that the other constituents of the air would vary greatly. We find that such is not the case for though oxygen is being constantly removed by the respiratory action of animals and plants the carbon dioxide produced is being consumed by plant growth and by the skeletal systems of various animals. Carbon dioxide is also greatly affected by being dissolved in bodies of water in the form of bicarbonates and being given up again to the atmosphere as carbonic acid when the partial pressure of the individual substances so determine. As a result of these complicated processes the proportion of oxygen on the surface of the earth varies only slightly and except under experimental conditions it is seldom reduced below 20 per cent.

In addition to its various gaseous constituents the atmosphere usually contains a greater or less proportion of minute suspended particles in the form of dust, the significance of which will be discussed in a subsequent paragraph; and finally in even the briefest review of the composition of the atmosphere we must mention living microorganisms, present only in very small numbers in pure outdoor air, as Pasteur demonstrated, but often increased to hundreds or thousands per cubic foot indoors or outdoors in wind storms or when considerable contaminated dust is present.

We may outline the changes that take place during breathing as follows:

a Respiration is essentially a combustion and there is consequently a diminution in oxygen. A man of average weight at rest consumes nearly 764 grams or 534 liters of oxygen in 24 hours.

b The carbon dioxide is increased and under the condition of rest about 840 grams or 427 liters will be produced in 24 hours if we assume the respiratory quotient to be 0.8.

c There is an increase of partially oxidized organic matter which is given off

from the body (chiefly from the skin, mouth and teeth) and which is of a nitrogenous nature. Among these substances are urea, certain aromatic fatty compounds and the like, which we recognize as the *body odor* and which is frequently so noticeable in a gymnasium.

d The humidity of the air is increased by moisture which is given off from the skin and from the lungs and nearly 1400 grams of water are thus evaporated in 24 hours in the case of a man of average weight at rest.

e There is an increase in the temperature of the air. Nearly 2600 calories are produced under the conditions cited above.

f Changes in dust and bacterial content also take place.

g The figures as above stated are from an individual at rest and in cases where there is physical activity the output of all of these substances is considerably increased and varies within very wide limits depending upon a great number of factors. It will be seen therefore that the changes in the air of rooms present a very complex problem, which may be extremely variable depending upon local conditions.

It may be helpful to compare the oxygen and carbon dioxide content of pure air, the air which we find in the lungs, the air which might be found in the worst ventilated rooms and that which can produce physical injury.

Oxygen and carbon dioxide content of different kinds of air:

	Oxygen	Carbon dioxide
Compositions of pure air	21%	.04%
Air in the lungs	16%	5.00%
The air in the worst ventilated rooms	19%	.40%
Composition of air which chemically produces physiological injury	14%	3.00%

The table will show that there is quite a difference between what might be called the vitiated air of a room and the air which can in a short time produce noticeable injury because of its chemical composition. It is frequently pointed out that the air in the worst ventilated room is chemically better than that which is in the lungs. Certain reference to this point will be made later.

From the lack of variation in the gaseous constituents of the atmosphere under more or less natural conditions, one is led to wonder if there has not been some definite design by Nature to keep these constituents within very close range. It is true that the living organism can adjust itself to changing circumstances provided those changes are made more or less gradually, for adaptability is one of the principal characteristics of living material. There is a rather serious question in my mind as to whether or not there is elasticity enough in the living organism to adapt itself within rather wide ranges of concentration of these various constituents, particularly when the changes are made extremely rapidly and repeatedly. This of course is a philosophical idea, but the danger of jumping too rapidly at conclusions has been emphasized time and again in science when we have known only part of the truth and not the whole truth, or have not had sufficient data to change our entire attitude toward the problem under consideration.

It may perhaps be well to consider separately and in some detail each one of the constituents of the atmosphere and the possible changes which may take place in each of them.

Consideration of the Various Constituents of the Air

Odors. Variations in practically each one of the constituent parts of the atmosphere have been given permissible upper limits, but for the most part these have been determined by a sense of feeling and therefore are not a truly scientific study.

With reference to odors and their effect on health Sedgwick in his Principles of Sanitary Science and Public Health says:

> There can be no doubt that evil odors may produce temporary sickness. On the other hand, there is no evidence whatever that typhoid fever or other infectious diseases can be directly caused in this way, so that while bad smells may be regarded as significant of putrefaction, decay, or even disease, and therefore useful warning of trouble, they cannot in the present state of our knowledge be regarded as true sources of infectious disease. If, however, the vital resistance be lowered by such smells, they may favor, even if they cannot cause, disease. But it does not follow that bad smells do necessarily, though they certainly may, lower the vital resistance, at least so far as this can be measured by the death-rate.[26]
>
> Dr. Ord reported to the Privy Council in 1859 that in 1858 (the year of the worst stench) steamboat men on the Thames suffered severely from languor, headache, sore throat, nausea, giddiness, mental confusion, etc. (in other words from symptoms of poisoning). In 1859 the river was much better, and very few such symptoms occurred: "The greater weekly mortality has not coincided with the greater development of the stench, our most ready measure of the foulness of the stream. In both years the presence of sulphuretted hydrogen in the river atmosphere was shown by the rapid blackening of paper soaked in solutions of lead, and by the discoloration of the paint of vessels." Second Report, Medical Officer of the Privy Council, for 1859, p. 55, London, 1860.[27]

It can be seen from this that even 50 years ago it was still held by some that odors might cause disease. *Miasms* were supposed to be generated by the decomposition of organic material and odors at the present time are frequently suspected of causing disease. During human habitation odors are given off from the mouth, teeth, skin, glands, clothing and the like, and these indicate a putrefaction which only takes place in the presence of an abundance of moisture. Bacteria, of the pathogenic variety, are not likely to be found present under these conditions. The principal significance of foul odors from the standpoint of public health is that it frequently indicates the presence of human excretions, and human excretions have associated with them sometimes the organisms of disease. There is some quite recent evidence that disagreeable odors are injurious to health in that they have a very definite effect upon the appetite; decreasing the amount of food consumed. They probably irritate or depress the nervous system and the mere fact that the olfactory nerve ceases to advise one of an odor which is continuously present and perhaps is increasing, means probably that the nerve has become insensible to a given odor but the depressing effect probably continues. The normal olfactory nerve will always detect a new odor or a different odor and for that reason the odor of the air on entering a room is a fairly good index of its freshness or staleness provided the air in the room is moist. Moisture increases odors usually and therefore odors become more objectionable as the air becomes more saturated with moisture. Irrespective of all other conditions which may obtain due to a poor ventilation it would seem that judging the atmosphere of a room from this point of view, we should have air which is not malodorous and of course this means a certain minimum change of air depending upon the many factors which would enter into the production of odors or the removal of the odors by some method of treatment of the air.

The obvious presence of odors led to the idea of the presence of organic effluvia under various terms, *morbific matter*, *crowd poison*, *anthropotoxin*, etc., which has been extremely difficult to overthrow. The work of Rosenau has failed to confirm the fact that an organic poison is present in the expired air. As stated before it seems to have been established that individuals when they have fresh

[26] Principles of Sanitary Science and Public Health, Sedgwick, p. 353, 4th Ed.
[27] Principles of Sanitary Science and Public Health, Sedgwick, p. 355, 4th Ed.

air use more food than when they have air of the same temperature and humidity which has been vitiated. Too, it has in the case of the lower animals been demonstrated that there is a less rapid growth curve in the first few days of their exposure though this effect is probably transitory.

Organic Matter. Hammond, Ransome, Seegen, Brown-Sequard, d'Arsonval, Rosenau and others have from time to time reported the presence of toxic substances in the air thrown off from the body. These organic materials if present in great amount may exert a depressing effect, which it is thought (together with odors) decreases the appetite and the inclination to work but this is probably not the most important factor.

Dust. Particles of solid matter are always suspended in the air and in the outdoors they are derived principally from smoke, from the dust raised by winds and the mineral matter ejected from volcanoes. The number of particles in each cubic millimeter is enormous and observers find hundreds of such particles on mountain tops while there are hundreds of thousands in the vicinity of cities.

Dust has an important effect on our comfort for its particles condense moisture; take up excessive water vapor from the air giving it back very slowly and therefore it has a great regulating effect. Each particle of mist and each rain drop has for its nucleus a bit of dust and if it were not for the dust, moisture would condense on the surface of the earth and our clothing and houses would be constantly wet. We know quite definitely that certain types of dust are usually met under rather artificial conditions and are highly injurious. Certain of these particles, the sharp pointed type of dust causes a fibrosis of the lungs, which is variously known as anthracosis, silicosis, and the like, according to the type of dust involved. There are a great many opinions relative to the effect of dust on lung tissue, but it is generally conceded that the so-called dusty trades predispose to diseases of the respiratory tract, especially tuberculosis. There is some question about soot and from certain studies in Pittsburgh it has been concluded that soot predisposes to pneumonia and perhaps that it lowers the death rate from tuberculosis. In certain industries, particularly where there is poisonous dust and fumes, carbon disulphide, arsenic and the like and where grinding and buffing wheels are used there is little question that excessive dust and poisons should be controlled. There are probably several ways of attempting this such as keeping down so far as the process may allow the production of dust and fumes; the wearing of respirators and the like; but in many of these dusty trades these conditions can be controlled only through specialized types of ventilation.

From all the evidence which is available it would seem that excess dust is not an asset in the atmosphere, and it would seem also that in cities we usually have quite an excess of dust over that which is found in outlying communities. The removal of such dust from the air we breathe if the process were a simple one and not too expensive would seem to be indicated.

Microorganisms. It has been noted that expired air is warmer and contains more moisture, but fewer particles of dust and bacteria than does the inspired air. When one talks, coughs or sneezes many bacteria may be thrown out in the minute globules of sputum which leave the respiratory tract. The number of bacteria in air is greatly increased when dust is raised and it is conceivable that under these circumstances, in rooms, particularly if they have been recently occupied by persons having certain types of disease, there is a distinct possibility of infection. The method of infection, particularly in diseases in which we find the organism in the respiratory tract is through the mouth spray and this is usually spoken of as droplet infection and is distinct from the old type of aerial infection.

Acid forming streptococci have usually been used as an indication of mouth spray and are frequently from two to four times as abundant in indoor air as in outdoor air. Most of the bacteriological work that has been done on air has been conducted from a quantitative rather than a qualitative point of view. It is a very indirect estimation of the character of the air in other words, and therefore such comparisons are open to rather serious criticisms. Diseases are often spread more directly in certain cases as in churches, schools and theatres, and other crowded places, but the contact there is a close one and should not be considered as air infection. Droplet infection is after all a most important means whereby organisms are disseminated from one person to another, because the implantation is so direct and the bacteria are not exposed to the untoward conditions of the environment for long. It is an exceedingly important means for the dissemination of those diseases, the causative agents of which are in the respiratory passages. Studies of the epidemics of measles, pneumonia, influenza at the cantonments serve but to emphasize this. That this is an important factor to consider under the head of ventilation goes without saying for where people are crowded closest together opportunity for droplet infection is greatest and this becomes by the very nature of the condition the place where ventilation should be best.

Carbon Dioxide. It is true that sometimes in deep mines and in old wells there may be such a high concentration of carbon dioxide that persons would perish because of oxygen starvation, but this condition is never met on the surface of the earth for even in the worst ventilated rooms and shops the percentage of oxygen in the atmosphere seldom falls below 20 because of diffusion, by leakage through the walls and the like.

While carbon dioxide may be looked upon as an end product of life it must be remembered that a certain concentration is absolutely necessary for the proper control of the respiratory center and if the gas is reduced too far in the blood, suspension of breathing may result which could conceivably result in a fatal manner. Gas exchanges take place in the lungs in response probably to the concentration of the gases on both sides of the capillary walls. If the air in the alveoli is not renewed carbon dioxide would increase in amount and oxygen would decrease, but this tendency is counteracted through the effects of breathing. We usually expel about one-fifth or one-sixth of the air contained within the lungs and as fresh air has a small content (0.03–0.4 per cent of carbon dioxide) and the expired air has about 4 per cent it will be seen that the air to which the blood is exposed in the lungs is at least as rich in carbon dioxide, as that which we breathe. The blood therefore by no means completely frees itself of all its carbon dioxide and contrary to early opinion, carbon dioxide does not seriously interfere with the capacity of the blood in the carrying of oxygen. If the carbon dioxide in the blood is increased, deepening of the respiration promptly results; as a matter of fact this control of the respiratory center is purely automatic.

Serious objection has been made by a number of individuals to the use of carbon dioxide determinations as in anyway criteria by which to judge the fitness of the air we breathe. These objections have been urged usually on the ground that carbon dioxide is not poisonous and that its continuous use as a test is misleading. We have no simple direct way of judging of the fitness of air, and certainly the determination of carbon dioxide is of value in a room in order to determine the rate at which the air of the room is diffused or of its replacement by outside air. It might be urged with just as much force that we give up the determination of nitrites and nitrates in our water supply, for they *per se* do no damage; so it might be urged that we give up B. coli determinations in our water supply to

determine its potability because B. coli if taken into the intestinal tract produces no disease condition. It might as well be urged that we give up the total bacteriological count in the milk supply. As a matter of fact all of these tests are but a means of arriving at a judgment and are not in themselves the end sought. Ability to interpret the tests in the light of other information is always necessary before any type of laboratory work is of value.

In the last 10 years opinions relative to the coli content of a water supply have been greatly modified and have been made much more stringent than formerly, but the test has remained practically the same and it may be that we shall find distinct use for some means of judging the rapidity with which air change is consummated, and to my mind no test for this purpose could be more practical than the determination of carbon dioxide.

Carbon dioxide is the most conspicuous product of combustion and it is only to be expected that it attracted a great deal of attention in the earlier days though it has been shown by many investigators since that carbon dioxide may be greatly increased and when other conditions are properly controlled the only apparent reaction of the organism is a 50 per cent increase in the rate of breathing and this occurs also with heavy exercise. The body's respiratory *factor of safety* is amply sufficient to take care of any variations in carbon dioxide content which may occur under normal conditions. Carbon dioxide is not poisonous as this term is usually used, but animals have been said to drown in carbon dioxide gas.

Oxygen. The double exchange of gas which takes place in the lungs is usually thought to be the result of the unequal partial pressures of the gas in the blood and in the air and in the lungs, and in the tissues. It is not known definitely that the exchange of the gas takes place according to laws of diffusion and whether or not other forces and actions are concerned. It has been shown that oxygen tension may be quite variable with different individuals under like conditions and that it is not the same in the blood of different animals under the same oxygen pressure. It is less in the cat's blood than it is in the blood of the dog, the horse or the human. Temperature undoubtedly affects this condition and with the same pressure less oxygen is absorbed at a high temperature. A subject of interest is the findings of Bohr, Haselbalch and others, that the carbon dioxide influences the manner in which oxygen is taken up in that as the carbon dioxide tension increases (within physiological limits) the oxygen taken up decreases. The laws of oxygen absorption must be determined by determinations upon the blood itself simultaneously with observations as to the temperature and carbon dioxide tension. It will be remembered that the alveolar oxygen tension is automatically regulated by changes in the respiration rate so that with great concentration in quantity of carbon dioxide the more the respiratory rate is increased.

The conditions as to the carbon dioxide in the lungs is, on the other hand, not quite clear. We have the advocates of the view that the gas exchange takes place simply because of physical laws and is therefore a diffusion process. Others claim that the lung is more or less of a gland in this respect and secretes gases and the gas exchange is therefore essentially a secretory process. There are undoubtedly a number of mechanisms that come into play under the various possibilities encountered but there are several points about which additional information would be valuable.

Temperature. It is a well recognized fact that the well being and ability to perform tasks of individuals are to a great extent influenced by their surrounding temperature. There are numerous occupations involving exposure to extremes of heat and cold, dampness and sudden changes. The human organism possesses the

faculty of maintaining a uniform temperature, *i. e.*, it so regulates and harmonizes the production and the loss of heat that the normal temperature of the blood, 98.6 deg. fahr., is not affected under ordinary conditions. In this the skin plays a most important part. Whenever cold acts upon the skin the stimulus is exerted primarily upon the end organs which transmit it by way of the nerves to the central nervous system (the heat regulating center). From there it is returned to the nerves governing the cutaneous vessels and muscular fibers; contraction takes place and because of a diminished blood supply there is a diminished heat loss. If, instead of cold, heat acts upon the skin we have dilatation instead of contraction of the cutaneous vessels, with an increased blood supply to the surface and a corresponding loss of heat by radiation and conduction. At the same time the sweat glands are stimulated to greater activity and more sweat is excreted and evaporated. By this means more heat is dissipated, but one of the ill effects of profuse or prolonged perspiration is that the blood loses some of its constituents. In this case, also, blood is taken away too long from the internal organs, and this changes the distribution of the blood supply and the nutrition of the stomach, lungs, heart and other internal organs is interferred with. Appetite may be lost and a vicious cycle set up that may have very far-reaching consequences.

The human organism endeavors to adapt itself to great extremes of heat and cold, but the ability of the body to maintain these conditions is by no means unlimited; the heat-regulating center may fail, or become inactive if the condition persists. This is especially true where we are dealing with repeated sudden changes of temperature. The dry-bulb temperature has been set and later the importance of the wet-bulb temperature has been emphasized, while the temperature of the two taking into consideration the movement of the air has also been used as a guide. It has been shown that high temperatures combined with high humidities corresponding to a wet-bulb temperature of 77 deg. fahr. and over, produce not only disagreeable but definite symptoms of physiological derangements with a rise in pulse rate and body temperature and a fall in blood pressure. Definite evidence as to whether or not such symptoms are present perhaps to a lesser degree, under the less extreme conditions which may obtain in occupied rooms and to what extent physical and mental efficiency are affected, has not been determined. It has been thought that exposure to drafts and low temperature which produce chill, particularly on individuals who live more or less constantly in an overheated atmosphere, is a factor in respiratory infections. Other observers think that the predisposing factor of low temperature to disease is not an important one and it has also been claimed that warm, dry atmospheres and warm, moist atmospheres are harmful to the mucous membranes, particularly those of the nose; that it conduces to nervousness, promotes infection and interferes with mental concentration. Homo-thermal animals have a heat regulating mechanism which is usually able to maintain a fairly constant body temperature even in an environment in which the temperature is not constant. The adaptibility of the body by means of this mechanism is frequently over-estimated for there are conditions which, as a matter of fact, are not rarely met, with which the heat regulating mechanism of the body is not able to meet. It is a matter of common knowledge that individuals at work get along best at a low temperature and if the work is not heavy or is of a sedentary character a higher temperature, say perhaps 68 or 70 deg. fahr. is most advantageous.

The effect of temperature solely may be summed up somewhat as follows: If the temperature varies from 40 and 65 deg. fahr. the feeling of cold is such that if the person is free to do so he will not remain quiet but will move about, thereby

increasing his body temperature by increased exercise and oxidation. If he cannot move about he may shiver; shivering is a form of muscular exercise which increases oxidation. The optimum temperature seems to be around 68 deg. fahr. and slight changes from this temperature do not call the heat regulating mechanism into play immediately, so that discomfort may be felt between 65 and 75 deg. This is probably because it is not so warm as to start active perspiration, nor so cold as to make one desire to exercise. Between 80 deg. and 100 deg. fahr. the body by the evaporation of perspiration and by radiation and conduction becomes cooler. It should be remembered that humidity greatly affects these factors though at this time we are considering temperature alone. It should be recalled that it was Haldane who said that the correct temperature, or effective temperature was indicated by the wet-bulb thermometer and that it is this latter temperature rather than the dry-bulb reading which determines the effects noted. When high temperature and high humidity are present it has been shown to be extremely dangerous. Soldiers have been known to suffer from heat stroke when marching in uniform even though the temperature was less than 70 deg. fahr. (increased humidity due to clothing).

When exposed to cold the first reaction of the skin vessels is blanching but a secondary reaction dilates them and this dilation acts as a protection to the part against freezing. This is similar to the primary effect of high temperature in which we get dilation of the blood vessels of the skin. The blood is thus concentrated at the expense of the inner parts of the body which condition gives the feeling of discomfort and drowsiness which undoubtedly is due to anemia of the internal organs, including the brain.

Continued exposure to such conditions undoubtedly leads to a lowered tone of the whole heat regulating mechanism and an inability on the part of the body to adjust itself to its environment. McConnell, Houghten and Yagloglou and other workers at the Society's Research Laboratory in Pittsburgh have placed subjects variously clothed and under a wide range of temperature, humidity and degrees of air movement and also under prolonged exposure of high temperature. They recorded restlessness, irritation, headache, palpitation of the heart, soreness of the eyes, dizziness, confusion, weakness and a tired feeling which persisted for sometime after the experiments had finished. The extreme dry-bulb temperature which could be endured was 157 deg. fahr. and 45 minutes while the extreme wet-bulb temperature was 122½ deg. fahr. for 35 minutes. But, under these conditions the body temperature rose several degrees and the pulse rate was markedly increased. They have shown that basal metabolism decreased with temperature up to 79 deg. with a 100 per cent relative humidity and then increased; the rise becoming very rapid when the experimental temperature is higher than that of the body 79 deg. fahr. with a 100 per cent relative humidity is clearly a critical temperature beyond which harmful results may be expected, and it would seem from their experiments that ideal conditions were found to lie between 62 and 69 deg. fahr.

It has been claimed that to a limited extent animal experimentation has shown that exposure to sudden chill exercises a predisposing influence toward infection. Certain phases of the summary reached by New York State Commission on Ventilation may be submitted in this regard:

1. Exposure to heat in the majority of normal subjects causes increased swelling, moisture, and redness in the nasal mucous membrane.

2. Exposure to cold, conversely, causes a diminution in swelling, moisture, and redness.

3. The effects of exposure to heat are more marked if the humidity of the air is high.

4. Definite reflex effects upon the nasal mucous membrane do not appear to be produced by exposing the surface of the body to extremes of temperature or to drafts.

5. Air currents or drafts striking directly upon the face materially modify the effects of changes of air temperature upon the nasal mucous membrane. High temperature with drafts results in a diminution of swelling and secretion, which would be expected in view of the cooling effect of air movement; but low temperature combined with drafts, while it causes pallor, leads to an increase rather than a decrease in swelling and secretion. This would appear to produce a moist and distended but anemic condition highly favorable to bacterial invasion and may be interpreted as a failure of a normal defensive mechanism under extreme conditions.

6. Workers subjected for long periods to high temperature and humidity, such as laundry workers, exhibit an atrophic rhinitis in an abnormally large percentage of cases. Workers exposed to drier heat, as in boiler rooms, also show a high percentage of atrophic rhinitis, but less than the group of workers in moist heat.

7. The nasal mucous membranes of such workers react to changes in atmospheric temperature and humidity quite differently from normal subjects, failing under ordinary conditions (as the normal nose fails under extreme conditions) to show the protective reaction of diminished swelling and secretion on exposure to cold.

8. Such circulatory reactions in the nasal mucous membrane produced by changes in atmospheric environment are too frequent and definite to be disregarded as a probable predisposing factor in promoting bacterial infection of the upper respiratory tract.[28]

The effect of temperature on resistance to disease has been cited in relation to the great infant mortality which is experienced during the summer months; temperature is, of course, only one factor which is operating here. Similarly, if one goes from a hot room to a cold room the mucous membrane of the nose becomes immediately pale. This leaves the membrane swollen and bathed with mucous secretions, but without its normal amount of blood and it would seem that this would be an ideal condition for the multiplication of bacteria. Apparently this is the phenomenon which lies at the base of the expression of *catching cold*. However, as most colds are due to an infection and as infection is rather a complicated problem; probably it is best expressed by Dr. Theobold Smith's old formula:

$D = \frac{mnv}{r}$. Where D is interpreted as the positive or negative production of the disease condition, m the specific character of the microorganism involved, n equals the number of infecting organisms; v equals the virulence of the strain and r equals the resistance of the host.[29]

Humidity. The influence of humidity upon heat loss from the body at different temperatures may be summed up somewhat as follows: If the temperature is low there is practically no perspiration and the body will lose its heat by direct conduction. If there is moisture in the air it will be deposited in the clothing and as moist clothing conducts heat away from the body more rapidly, moist air seems cooler than dry air of the same temperature.

The question of humidity is as has been stated above, suspected to be a factor in predisposing to respiratory infections and it has also been stated that it causes abnormal conditions of adenoids and tonsils and may be conducive to nervousness. That the *sensible temperature* is not indicated by the temperature of the dry-bulb thermometer must be apparent from these considerations relative to humidity and it would seem that the *sensible temperature* would more closely correspond

[28] Report of New York State Commission on Ventilation, p. 163.
[29] The Teaching of Hygiene, Rush, American Journal of Public Health, June, 1925.

to the temperature indicated by the wet-bulb thermometer. It can be seen that within certain limits increase in the humidity might allow for a decrease in the temperature of living rooms. The average daily amount of water eliminated by the skin is nearly $2^1/_2$ lb. and from this it will be seen that the question of evaporation and hence humidity is an extremely important one.

McConnell in a recent paper relative to hospital ventilation said that:

> Humidification of the air is equally important, especially in cold climates. In winter the humidity indoors may be as low as 10 per cent, while in summer it often reaches 80 per cent. The average temperature outdoors during the winter months, from December to March, in eastern localities is about 35 deg. fahr., resulting theoretically in a reduction of its humidity to 16 per cent. Such a low humidity sometimes causes nervous irritation and discomfort due to excessive evaporation from the respiratory passages and the skin. On a zero day with an average relative humidity of 50 per cent outdoors, the air must be heated to about 75 deg. fahr. Under this latter condition the relative humidity is reduced to the extremely low value of about 2 per cent. While this air is warm enough for comfort, it is enervating because of its high temperature and its great capacity for taking up moisture. Complaints are frequently made that such an excessively dry condition of the air causes undue parching of the throat and considerable discomfort, and some authorities believe that it predisposes to respiratory diseases.[30]

From these statements relative to humidity it must be apparent that humidity is quite a variable factor in the air supply. That it should be kept within certain limits seems apparent from the evidence that we have relative to its physiological effects and possible predisposing influence. It is thought that some provision should be made for humidification because humidity of the outdoor air is not always suitable especially when we have to heat it thereby reducing the relative humidity considerably.

Air Movement. The pioneer experimental work done in calorimeters, as previously stated, showed that it was not the increase in carbon dioxide nor the decrease in oxygen nor the presence of *morbific matter* that gave rise to the feelings experienced and these experiments demonstrated beyond question the great importance of movement to move the *aerial blanket* which surrounds the body. Air movement increases the conduction of heat and moisture and therefore has a cooling and an exhilarating effect like that which one experiences in stepping out into open air on a day when there is a gentle breeze. The atmosphere of a close, unventilated room on the other hand is practically motionless and a blanket of warm moist air surrounds each person who is in the room acting in the same manner as does a typical sultry day in mid-summer.

We have discussed these facts in sufficient detail to show that the problem of ventilation is a complex one, that there is a need for the removal of odors and excessive dust, that there should be an attempt to control droplet infection by methods of ventilation so far as that may be possible, that carbon dioxide while in itself not poisonous, is perhaps not an extremely desirable material in high concentration. Though individuals may survive in experimental chambers for short periods of time under decreased oxygen and increased carbon dioxide and increased humidity is true, but that these are extremely desirable conditions and that they are more suitable for the living organisms than conditions simulating those of outdoor air, no one is foolish enough to believe. That the control of temperature, humidity and air movement may control all of the other factors entering into the problem of ventilation is a fairly complex one with a good many interacting factors to be considered goes without saying. Take into consideration the lack of constancy

[30] Hospital Ventilation, W. J. McConnell, M.D., Modern Hospital.

in temperature, humidity, dust, etc., in the out door air and it will be seen that the getting of air into a building and having it meet certain desirable specifications is a good deal of a problem. That all of the factors concerned in ventilation are not very satisfactorily answered at the present time must be apparent from the foregoing statements.

Opinions. Toward the beginning of this paper reference was made to the fact that sometimes experimental work will be quoted by a number of individuals and for that reason it will appear to be more authoritative. Perhaps no work is more widely quoted by various persons than the work of the New York State Commission on Ventilation and practically all of our popular texts in hygiene base their discussions on it. There are also one or two popular books that consider the problem of ventilation and they take their data directly from the work of the New York State Commission on Ventilation. Particularly that part of the report which has to do with the health of school children has attracted a good deal of attention, and perhaps some quotations from this report might be interesting. Work has been done in other places showing the relation of ventilation to the health of pupils in a school and it seems only fair to cite a number of these.

My old friend Dr. John Hurty who was before his death for many years Health Officer of one of our larger states estimated that 20,000 school children out of 500,000 had tuberculosis. He emphasized the point that if these children were taken out of school and given the proper treatment for tuberculosis the greater majority of them would get well. He further estimated that 3000 of those children were doomed to die, "Killed in school," as he put it and he emphasized that one of the most important factors causing these deaths was lack of proper ventilation.[31] Hurty's discussion was in relation to the importance of ventilation in school buildings.

It seems to me that we have treated our facts and figures and established our standards for healthy individuals while the question of surrounding the average individual with conditions that will tend to make him strong and healthy is what we have got to take into consideration for most individuals die of disease rather than age, or as it has been so well stated by Montaigne; "To die of age is a rare, singular, and extraordinary death."[32]

In discussing the main object of ventilation, Winslow and Williamson say:

> The main object of ventilation is to maintain a supply of cool air and to remove the air that has been overheated by the bodies of the occupants. It is difficult to attain this end in cold weather by the use of ordinary windows alone without producing drafts. On the other hand, the New York State Commission on Ventilation found that ideal conditions could be maintained by drawing fresh air through windows especially equipped with slanting window boards to deflect the air current upwards and with radiators below the windows to temper it, and by permitting the vitiated warm air to escape from the upper part of the inside wall through a gravity exhaust duct. Where for any special reason it is impossible to keep the windows open, mechanical or fan ventilation may be used. Fans are essential in the ventilation of auditoriums and of many crowded factory workrooms.[33]

While Professor Winslow has said in the JOURNAL OF THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS that:

> Ventilation in the modern sense is conceived primarily as a procedure for removing the excess heat produced by the human body and replacing it by fresh air that is cool but not too cold. The amount of air needed for this purpose will obviously bear no

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[31] TRANSACTIONS AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Dr. Hurty, Vol. 15, 1909, p. 224.
[32] Principles of Sanitary Science and Public Health, Sedgwick, p. 3.
[33] The Laws of Health, Winslow and Williamson, pp. 89–90.

necessary and direct relation to the number of persons in a given confined space unless we also take into account the opportunity for direct heat loss through walls and ceiling. Under these conditions, as, for example, in an interior auditorium with no appreciable heat loss, the standard of 30 cu. ft. per minute will prove substantially correct. An average adult gives off, as, a result of oxidations within the body, approximately 400 B.t.u. of heat per hour and this is almost exactly the amount of heat necessary to raise the temperature of 30 cu. ft. of air from 60 to 70 deg. In factory workrooms where there are special heat sources such as forges, furnaces and annealing ovens, the amount of air necessary to maintain good ventilation may be materially more than this. I have in mind a particular annealing shop where 30 changes of air per hour were affected with notably successful results. On the other hand where the room is relatively small and has one or more outside walls the necessary air change may be materially less. It is this condition which obtains in the ordinary schoolroom and it is in connection with school ventilation that a radical revision of our earlier view points is most clearly indicated.[34]

Dr. Newsholme[35] is of the opinion that 1500 to 1800 cu. ft. of fresh air per hour is necessary in the average schoolroom. He feels that the problem of ventilation is rather difficult because of the fact that the rooms are considerably crowded, may be occupied continuously for three hours and that the air should be changed 12 times an hour winter or summer if it is to remain clean and fresh. The attempt should be made to regulate the temperature of the classroom to about 60 deg. fahr. and he states that no natural agencies are sufficient to accomplish this.

Parkes and Kenwood state that:

> Educational results are in no small measure dependent upon the air results, and insufficient air renewal in school classrooms is an important item in determining school fatigue. The mental and physical depression caused by the insufficient air renewal cannot be explained by the increase in carbonic acid. It is doubtless due to the increased temperature and humidity of a stagnant atmosphere, being responsible for an interference with the heat-regulating mechanism of the human body. It is important, therefore, that the wet- and dry-bulb temperatures of school classrooms should be continuously recorded, and that an effort should be maintained to keep the dry-bulb temperature between 56 and 60 deg. fahr. and the wet-bulb temperature between 53 and 56 deg. fahr.[36]

In Experiments on Humidifying Air in the Oliver Wendell Holmes School, Dr. Harrington submitted the following report of the effect of increased humidity upon the mental and physical conditions of the pupils:

> 1. On the basis of similar mental tests conducted upon pupils occupying similar grades on both the moist and dry sides of the building no appreciable difference was found.
>
> 2. The three rooms on the moist side had a percentage of attendance of 100; the percentage of attendance of all teachers on the moist side was 100; on the dry side the percentage of attendance of pupils was 97 per cent.[37]

Frank G. McCann in a recent volume of TRANSACTIONS OF THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, writes as follows:

> In years past, under normal conditions, many of our mechanically ventilated plants, run by intelligent and conscientious janitor-engineers, showed excellent conditions and teachers and principals not only were satisfied but actually demanded that mechanical ventilation be provided during the colder months.
>
> Some years ago a careful survey was made by Dr. Luther Gulick of the Sage Foundation, as to relative effects of the various systems of ventilation on pupils of our schools, as shown by promotions, etc., and this showed a markedly higher rate of promotions in mechanically ventilated schools than in gravity or open-window ventilated schools.

[34] JOURNAL OF AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Prof. C.-E. A. Winslow, March, 1926, p. 117.
[35] Hygiene and Public Health, Parkes and Kenwood, 6th ed., p. 604.
[36] Hygiene and Public Health, Parkes and Kenwood, 6th Ed., p. 605.
[37] Experiments on Humidifying Air in the Oliver Wendell Holmes School, Dr. Harrington, TRANSACTIONS AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 19, 1913, pp. 122–123.

This was by averages of all the schools in a class, being for one hundred or more buildings in each class, and not making any allowance for antiquated installations. It is believed that a comparison based on properly equipped and properly operated schools would show even more clearly, the advantages of mechanical ventilation.

The tests made in our schools by the Department of Health of this city and reported by Dr. S. Josephine Baker of that Board in February, 1918, were carried on under conditions which render them of little value except as evidence of improper conditions, shown thereby to exist under present methods of control.

No attempt was made in such tests to confine the study to modern schools, equipped with well-designed and well-operated plenum installations, as compared with modern schools having only window ventilation. The schools selected were of all types and ages and no special supervision of operation was given, hence so many variable factors enter into the causation of the noted readings that it is impossible to deduce therefrom any reliable data of the effects of plenum ventilation as compared with window ventilation.

As an endeavor to better conditions by unifying control of design, installation, maintenance, operation and fuel supply, heretofore handled in separate and largely unrelated bureaus, our Board of Education has recently appointed a Superintendent of Plant Operation, who will in the near future have control of all of the above matters, thus making better control and assuring better operating conditions. Much is hoped from this change.[38]

In her work on Child Hygiene Dr. S. Josephine Baker states relative to the experimental work in the New York School conducted during the winters of 1915 and 1916:

1. Schoolrooms ventilated by windows alone, without gravity exhaust ducts, are likely to be imperfectly aerated and malodorous.

2. Schoolrooms ventilated by windows without special deflectors and by gravity exhausts are much better than those which lack exhaust ducts.

3. Schoolrooms provided with certain types of window deflectors, with radiators located beneath the windows and with exhaust ducts, may be ventilated throughout the winter season with entire success. Under many circumstances this may be accomplished without the use of fans and with the maintenance of agreeable conditions satisfactory to teachers and expert observers. In judging the results of these experiments it should be noted, however, that the practical experience of members of the commission has suggested that proper dampering is essential to avoid back draughts. In some cases the installation of exhaust fans may be desirable in order to maintain a positive exhaust, especially during the period of milder weather and when the wind pressure is slight or in an unfavorable direction; such fans should, however, be designed to produce only a slight air flow or the special virtues of the window system may be lost.

4. Window deflectors composed of parallel curved plates are somewhat superior to those of the simple plate-glass type. The plate-glass deflector should be of ample height.[39]

The New York State Commission on Ventilation comments upon this study as follows:

There are indications that something inherent in the method of ventilating schoolrooms by means of forced draft and gravity exhaust, as practiced in this study, is productive of respiratory affections to an extent not present in rooms ventilated with windows and gravity exhaust. What the unfavorable elements are, is not entirely clear. Higher temperature is undoubtedly the main factor. Another is the greater uniformity of temperature and air flow, characteristic of the fan rooms. Too great uniformity perhaps removes a desirable stimulating effect which exists when temperature and air movement fluctuate as in the window rooms.***

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[38] F. G. McCann, TRANSACTIONS AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 26, 1920, pp. 74–75.

[39] Child Hygiene, S. Josephine Baker, pp. 317–318.

It must not be inferred that window ventilation, as represented in this study, was uniformly satisfactory. It was not. As a rule, rooms exposed on the east do not fare as well as others. Ample exhaust openings are better than those of small area. The location of outlets with respect to the windows, location, size, the type of heating system and control of direct radiation, window deflectors, etc., affect the success of this method. Yet in spite of our inadequate knowledge of window ventilation at its best, the fact remains that the window rooms of this study, even though of crude arrangement, and not built originally for the purpose, competed on favorable terms from a hygienic and esthetic standpoint with the more elaborate and costly fan and duct equipment. The tendency in the past twenty years has been away from natural and toward mechanical ventilation. The time and effort of the heating and ventilating engineer have been directed toward the perfecting of mechanical means for aerating buildings. It is possible that the same amount of effort if expended on the development of window ventilation would yield results of great value.[40]

Later Dr. Baker, in discussing the question relative to costs in the two types of rooms used in the experiments, says:

The question of added cost of heating, therefore, need not be considered as an argument against the open-window method of ventilation.[41]

Experiments conducted in certain of the schools in Pittsburgh, Pa., and reported in the TRANSACTIONS of the SOCIETY[42] show that with mechanical ventilation there was noted a decrease in respiratory diseases. In view of the fact that Pittsburgh has the highest pneumonia death rate in the country this might be a profitable field for further study.

In quoting the results of absences and disease in the schools under observations for the New York State Commission on Ventilation Report, Winslow says:

Respiratory diseases among pupils in attendance were least prevalent during the first year in the coldest group of rooms, but absences due to respiratory disease in this year and both absences and cases of respiratory disease among pupils in attendance during the second year were least in the rooms averaging 66.6 deg. fahr. In every instance the warmer rooms (although they only averaged between 2 and 3 deg. higher than the middle class) showed a very materially higher respiratory disease rate than either of the other groups. Other factors than mean temperature that may have entered into these results will be discussed below.[43]

Later in his discussion he says:

It has been claimed that very dry air was an important predisposing cause of respiratory disease, and that it was conducive to nervousness and general bodily discomfort. In considering the influence of dryness, as in the case of temperature, we must take the factor of air movement into account. There has been much loose talk about schoolrooms "drier than the Desert of Sahara;" and it is true that the air of heated schoolrooms in cold climates does often show as low a relative humidity as desert air. *** Such experimental results which are available in regard to the supposed harmful effect of dry air *per se* are almost wholly negative. The New York State Commission on Ventilation devoted a considerable amount of time to researches along this line. Direct observations of the effect of various atmospheric conditions upon the nose and throat showed that hot moist air was worse than hot dry air, and this conclusion was borne out by the fact that laundrymen, exposed to hot, moist air showed a higher percentage of atrophic rhinitis than furnace men exposed to hot, dry air.[44]

In extensive investigations the Commission failed to establish in the question of nervousness and the health and the intellectual progress of school children that no effect of dry air could be demonstrated. The humidity in various studies

[40] Report of New York State Commission on Ventilation, p. 451.
[41] Child Hygiene, S. Josephine Baker, p. 322.
[42] TRANSACTIONS AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, Vol. 26, 1920, p. 74.
[43] Public Health and Hygiene, Park, pp. 254–255.
[44] Public Health and Hygiene, Park, pp. 255–256.

ranges between 20 and 50 per cent in the cabinet experiments and between 29 and 42 per cent in the schoolrooms.

The most favorable mean relative humidity for the 24 hours as indicated by his graphs is 80 per cent of saturation, which would perhaps correspond to a midday humidity of 60 to 65 per cent. It may be that the brief period of the New York experiments and the relatively small number of subjects was insufficient to reveal detrimental effects which were really present. On the other hand it is equally possible that the comparatively slight variations in humidity which it is possible to obtain by artificial humidification when operating for the short period of the school session, do not really exercise such influences as are manifested by climatic variations extending over the whole 24 hours.[45]

In discussing the effect of outdoor air, reference has already been made to Trudeau's work at Saranac Lake in 1873, and similar work by Brahmer and others abroad.

Graham Lusk, in his Science of Nutrition, quotes Wolpert as follows:

It is shown quite definitely that wind and humidity have an exceedingly important effect on metabolism.[46]

Baker and Sprunt in The Degenerative Diseases write as follows:

In spite of the recognized importance of the purely physical factors of temperature, humidity, and motion of the air, conservative sanitarians are unwilling to exclude other possible harmful influences in vitiated atmosphere and insist that good ventilation necessitates some admixture of outside *fresh* air. Fortunately for us, some air comes in through the little cracks around windows and doors and even through the masonry of the walls, though papering and painting of the inside walls greatly lessen this means of air exchange. There are elaborate methods of ventilating large buildings, which are quite satisfactory when properly installed and operated; but in most houses and workrooms dependence is placed upon *natural* ventilation through windows and doors. For efficient ventilation there should be openings in opposite sides of a room, and this is often difficult to secure without draughts, which cause most people discomfort. There are many simple devices that may be used in windows to deflect the air upward, or which may be placed at the top of windows to facilitate the exit of vitiated air.

Life in the country and the *back to the farm* movement are distinctly unpopular in America today. More and more people are crowding into the cities, where the method of living, especially in winter, involves the spending of the largest part of their hours awake in poorly ventilated quarters. Fortunately, the crusade against tuberculosis has taught many people the value of fresh air. The insurance of a satisfactory night supply by the use of sleeping porches, window tents, or even by widely open bedroom windows does much to counteract the lack of satisfactory ventilation during the day. In the daytime windows should be kept widely open in summer and partly open in winter, except in bitterly cold weather. A good deal may be accomplished in winter by watching the house thermometer and making sure that the thermometer remains close to 68 deg. fahr. or slightly lower. Unfortunately, there is no simple satisfactory and practicable method of securing a proper amount of atmospheric moisture in houses heated directly by steam or hot-water radiators. A fairly simple and partially effective method is to open the house as widely as possible several times during the day for 15 or 20 minutes at a time to ensure a thorough change of air. As a rule, times for such a procedure can be found in most households without inconvenience, and the better health resulting will more than compensate for what is lost through the increase of the coal bill. Heating and lighting methods have distinct bearings upon ventilation. Even a small fire in an open fireplace is a valuable adjunct to the ventilation of a room by furnishing a passage for rapid egress of the air and the creation of gentle currents in the atmosphere of the room. Electric lighting is to be preferred to gas or to oil lamps.[47]

Quoted from *The Nation's Health:*

Window ventilation, as advocated by the New York State Commission on Venti-

[45] Public Health and Hygiene, Park, p. 257.
[46] Science of Nutrition, G. Lusk, p. 146.
[47] The Degenerative Diseases, Baker and Sprunt, pp. 65-66.

lation, is not cheaper than the plenum method, states Samuel A. Challman, as reported by *The Heating and Ventilating Magazine*. In fact, the term *window ventilation*, is a misnomer, for as commonly employed it connotes ventilation by simply opening windows. But the New York plan makes several requirements as to equipment and operation which include the increasing of the classroom space from 3 to 6 per cent, and the elimination of any window on the east side of the building, increased radiation, and vent ducts more than doubled in size. Blower or heat ducts are eliminated, but, according to the author, this is the only saving over the plenum system. He says further: "The report of the commission also states that no detailed investigation has been made as to the cost of this window ventilation system but that it seems reasonable that the cost of extra radiation and window boards would be more than balanced by the ducts and fans required in the plenum method." The author disagrees with this conclusion.

The commission, in its report, gives six requirements which the *Heating and Ventilating Magazine* reports:

1. Under the lower sash there is to be inserted a *deflector* providing for a horizontal entry of air and a vertical discharge, induced by a series of parallel curved plates (p. 335).

2. Beneath this deflector there must be a *radiator* extending the full width of the deflector for the purpose of heating the air discharged from this deflector (p. 521).

3. On the wall opposite the windows, *exhaust* ducts with a total cross-section area of 8 sq. ft. for a schoolroom of standard size must be provided (p. 522).

4. Instead of the usual allowance of 192 cu. ft. of space for each pupil, this method calls for from *250 to 310 cu. ft.* for each pupil according to age, the larger space being required for the older pupils (p. 522).

5. The temperature of the room is to be kept at 67° F.

6. *An eastern exposure* of windows is unsatisfactory as it does not give the full advantage of prevailing winds (p. 384).

But even if all these conditions are met, the commission hesitates to give it unqualified approval as it specifically states (p. 528). "There will be many schools in which this method cannot be applied. Where noise, dirt, and odors from the street make it inconvenient to have the windows open, the use of the plenum system would, for instance, be clearly indicated, and where classrooms are markedly overcrowded *window ventilation* would prove *inadequate*."[48]

It may be of interest at this point to quote from some of the authorities on physiology and physiological chemistry. Howell, one of the foremost authorities on physiology, writes:

> It is generally recognized that in badly ventilated rooms the air acquires a disagreeable odor, perceptible especially immediately on entering, and that persons remaining under such conditions for any length of time suffer from headache, depression, and a general feeling of uncomfortableness. It has been assumed, although without sufficient proof, that these effects are due to the vitiation of the atmosphere of the expired air.[49]

and later

> Under the ordinary conditions of life poor ventilation produces its obviously evil results in rooms temporarily occupied—schools, churches, lecture rooms, theatres, etc.—and it is important to know what is the cause, and how it may be avoided.[50]

In discussing the question of oxidizing enzymes Wells writes:

> Although oxidation of organic compounds is the chief source of energy in the animal body, yet the way in which it is accomplished is very little understood. We only know that it is brought about within the cells, and that substances that outside the body are oxidized with difficulty, are completely oxidized to carbon dioxide and water within the cells, and that this is done with just such a degree of rapidity that the heat produced

[48] Window Ventilation Does Not Save Money, *Nation's Health*, June, 1926.
[49] Text Book on Physiology, Howell, 3rd Ed., p. 645.
[50] Text Book on Physiology, Howell, 3rd Ed., p. 645.

is in exactly the amount necessary for the wants of the body. There can be little question that this oxidation is accomplished through catalytic agents acting within the cells, and certain of them have been obtained in a condition permitting of study. As yet their exact relations to intracellular oxidation are not clearly defined, but for the present they may be grouped provisionally as oxidizing enzymes. That some of them are highly specific is shown by those disorders, such as alkaptonuria and diabetes, in which the body loses the power to oxidize a certain chemical substance while retaining the normal power to oxidize innumerable other substances. Of the oxidizing *enzymes* as yet identified none can be considered as of importance in the energy-producing oxidations of the body (Battelli and Stern); all the enzymes of this class yet known being apparently concerned with less essential oxidation of food-stuffs may not be dependent on enzymes.

According to Lillie the oxidative processes in cells take place most actively in relation to the membrane surfaces (or phase boundaries) of the cells. The studies of Meyerhof and Warburg indicate that intracellular respiration occurs on the structural surfaces of heterogeneous systems containing iron, *i. e.*, by surface catalysis. It is also possible that substances capable of taking up H from water may be responsible for oxidation, because of the coincident setting free of available oxygen, and these substances with such an *oxidoreductase* effect may not be enzyme but relatively simple compounds.[51]

The above quotations show the lack of absolutely definite statements from the point of view of the physiologist and physiological chemist, which individuals are better prepared than any others to speak with authority on the changes occurring in individual cases where experiments have been of rather short duration. If we have no specific data in these fields and we have to resort to study of large groups over long periods of time, namely, by the statistical method, great care should be taken in the selection of our groups, at all points in the study, and we should be sure that the conclusions are warranted by the data collected. If the method at present in operation had been productive of unhealthy conditions in large numbers of people it would surely have been noted ere now, even by the casual observer. One would suspect under the circumstances that such is not the case, and any change from our present admittedly empiric standards is only to be made after conclusions that have been arrived at by one set of observers in one locality have been checked by several other observers in different localities. Only by this means will conclusions arrived at by the statistical method prove convincing.

Climate of and by itself is undoubtedly a secondary consideration. While not everyone can choose the best climate in the world, after all the main advantage of fresh air can be enjoyed in almost any locality. In the city outdoor air is, under ordinary conditions, very invigorating and the air at the top of skyscrapers is especially free from street contamination. The common prejudice against damp air is greatly exaggerated, while moderate humidity of air is advantageous. It seems to many that to live in damp, even foggy, out-of-doors is in general more healthful than to live indoors with improper ventilation. The custom which is almost universal abroad when the weather permits, should be encouraged in this country, that is, eating out in the fresh air. There is little doubt that if the prevailing ideas as to the real value of fresh air could be modified radical adjustments in living and working conditions would be made. Outdoor occupations should, when possible, be chosen in preference to indoor occupations, particularly in individuals who are not very healthy, and physicians almost universally agree that out-of-door air is better than indoor air for invalids and especially for those suffering with tuberculosis. The benefit from being out-of-doors is not only due to the air which of course has a more or less variable temperature, which possibly serves

[51] Chemical Pathology, Wells, 5th Ed., pp. 50–51.

as a stimulus and tonic to the system but may be due in some measure to sunlight and other conditions too. Fresh air usually has a sedative effect and stimulates the appetite. Huldschinsky[52] in 1919 showed that by the use of the quartz mercury vapor lamp or with the sunlight treatment rickets could be cured. It had previously been demonstrated that cod-liver oil was a very valuable treatment in this disease, though the connection between cod-liver oil and sunlight treatment was not very clear. This is another condition in which more scientific investigation is necessary before a definite conclusion could be reached.

We have already discussed the value of the various factors that could be considered relative to the problem of ventilation. It must be remembered that the mere construction of the proper kind of building does not insure ventilation and that with ideal window space or ventilating apparatus unless they are actually used no benefit is derived. There seems to be an unreasonable prejudice against air in motion for it would seem that from the outdoor treatment of disease a gentle draft is as a matter of fact one of the best friends that the sick person may have; a strong draft directed against a small area of the body which is sufficient to produce a local chill is not desirable. It goes without saying that a person in a perspiration should not sit in a strong draft. The popular idea that colds are derived from drafts is greatly exaggerated, for the average cold is undoubtedly a germ disease. There is possibly a predisposition to cold from drafts and perhaps from a thousand other conditions which we may speak of as lowering the vital resistance. It is only the presence of germs plus a draft or some other condition which produces the cold. Most colds probably result from some other infection or from some one who is already suffering with the condition.

There are two general methods for ventilation, the one, the so-called *natural* system, is usually accomplished by opening the window. This is probably of great value under ordinary conditions in houses, but the system is usually inadequate for schoolhouses or meeting halls, where great numbers of people congregate. The artificial systems of ventilation are those which are usually installed in connection with heating systems. This is the type that are usually found in large buildings and schools, meeting halls, churches and the like and the ventilation is accomplished either by the plenum system, in which the air is forced into the rooms, or by the vacuum system in which the air is exhausted from them, or by a combination of the two methods. Various modifications of these systems have been instituted from time to time in which the air may be washed, or screened, or humidified, or some of it may be recirculated. Most of these systems are based on a unit which attempts to supply 30 cu. ft. per minute per person.

In comparing the two methods, namely, *open window* ventilation and *artificial* ventilation, it will be noted that the former is by no means a controlled process, while the latter, if properly constructed and properly operated, should be able to meet any type of conditions that are likely to be placed upon it. The former is haphazard or is dependent on chance while the latter is under control. No provision can be made in natural ventilation for the conditioning of the air unless it is the one factor of increasing its temperature, and we have noted that there are many factors in the problem of ventilation. The old method of ventilation by open windows has been found inadequate to meet conditions that obtain in schools, meeting halls, churches and large buildings and hence it has been discarded. In discussing the questions relative to the points which should be observed in modern mechanical ventilation McConnell makes the following statements:

[52] Fresh Air and Ventilation, Winslow, p. 17.

1. The equipment should have ample capacity to meet the special conditions of the particular hospital.

2. The incoming air should be washed and its moisture controlled in its passage through a central air washer.

3. The conditioned air should be distributed to the different wards through a pair of ducts, one for warm and one for cool air. The dampers of these ducts are controlled by individual thermostats in each room thereby permitting a mixture of warm and cool air in any desired quantity. In this way any particular temperature may be accurately maintained in certain wards or departments while different temperature conditions may be had in others.

4. The air distribution in wards should be uniform and thorough; objectionable drafts can and should be avoided.

5. Recirculation of the air should be used with a caution.

6. Provision should be made for artificially cooling the air in warm weather, taking advantage of the cooling effect obtained by the evaporation of water in the air washer. If further cooling is desirable refrigeration is necessary.

According to the engineering data available the initial cost of installing heating equipment alone, without any ventilation whatever, amounts to about 8 per cent, more for mechanical ventilation and air conditioning, bringing up the total to 17 per cent of the cost of the building. This estimate is applicable to cold climates where part of the heating is furnished by the ventilating system and the remaining part is supplied by direct radiation, through the medium of radiators placed under the windows of individual rooms. In mild climates the ventilating system, as a general rule, takes care of all the heating and the combined cost for heating and ventilation is reduced to some extent.

Now, if we take into consideration the fact that the space per occupant can be reduced by using a mechanical system, thus requiring a smaller building or accommodating more people, the result is a significant reduction in the cost of the building. Where window ventilation is used more space must be heated. It is estimated by ventilating engineers that for a mechanically ventilated school in a cold climate the cost of the entire building is 15 per cent less than the cost of a building using window ventilation.

The yearly expense of operating, heating and ventilating a building is perhaps slightly less when window ventilation is used than when a mechanical system is used, but considering the increased capacity for occupants in a mechanically ventilated space the cost per occupant will be materially higher in the window ventilated spaces.[11]

Recently a modification of the regular type of natural ventilation which as above stated is really uncontrolled ventilation has made its appearance under the misnomer of *open window* ventilation. The open window is by far the most insignificant part of this system for the windows must be supplied with a certain type of deflector, radiators must be placed below the window and the surface of radiation is nearly doubled, while the duct for carrying off the air from the room by gravity is much larger than that usually used and frequently has to be equipped with a fan. After we have arrived at this point we must take cognizance of the fact that a room so equipped must decrease the number of students which similar sized rooms mechanically ventilated now care for, and taking all of these factors into consideration it will be seen that what we are dealing with is not a method of open window ventilation but an entirely new system of ventilation which in its last analysis is probably more expensive than the mechanical system and in its operation is not more satisfactory than natural ventilation, because it is still uncontrolled ventilation. It has been admitted by its advocates that it will only work satisfactorily under special sets of conditions and that the position of the room according to the point of the compass and the direction of the wind, and the outside temperature and the like seriously affect its operation. If we could control

[11] Hospital Ventilation, W. J. McConnell, M.D., Modern Hospital.

the outside air with respect to humidity and temperature and all that which we desire within the room, there would probably be little difficulty in the operation of such a system, but this would be merely shifting the control to the outside of the building in an attempt to produce ideal conditions for this new type of ventilating system. This system has been tried out in a few places and has but one constant advantage so far as I am aware and that is the effect of the psychology of the open window. Comparative results announced in the Report of the New York State Commission on Ventilation (a document not at all acceptable to heating and ventilating engineers generally) between a window ventilation and a controlled system of mechanical ventilation seem to indicate that the uncontrolled method is preferable.

The arguments against a controlled method of ventilation are rather numerous and it must be admitted that ventilating systems have been built that do not ventilate, and it must further be admitted that the ventilation plant in order to work properly must have a certain amount of supervision. One would hardly think of complaining about a watch that he had bought not keeping time because he neglected to wind it. The criticism is again made that the individual who is charged with operating the plant does not tend to his business. Shifting the responsibility from one person to many, and having them watch three or four windows and radiators and a thermometer in addition to the work of teaching "the young idea how to shoot," is hardly a solution for the problem. From certain schools, in which this method of uncontrolled ventilation has been installed, anything but optimistic reports have been received.

There is little question that the opinion of most people in regard to air conditions is of rather limited value. In old Hunginton Hall at The Massachusetts Institute of Technology where there was no ventilating at all, some blind registers were set into the wall behind which electric fans were placed and as the fan blew the streamers out from the register people who before were exceedingly uncomfortable were now at perfect ease. Just why we should limit our observations in the comparisons of standards in rooms equipped with these two different types of ventilation to report only respiratory illnesses is not quite clear. There is a very great danger in reaching conclusions from one set of experiments, particularly where some of the conditions under which the experiments were conducted are open to question. In ventilation as in other matters affecting the health we should err on the safe side if we are going to err at all, and apparently from our present knowledge of ventilation there is much to be learned before any radical change of standards is possible.

Mr. D. D. Kimball, a member of the New York State Commission on Ventilation, summarizes the limitations of uncontrolled ventilation in the following manner:

1. The method applies to buildings of small or moderate size.
2. The method may frequently cause "back drafts."
3. The method may not be used in buildings located in dusty and odorous surroundings.
4. Teachers cannot be relied upon to keep the window openings properly regulated.[54]

One application of ventilation installation which merits more attention than it has received in the past is the possibility of artificial cooling of the air of occupied places in warm weather. We seldom think of cooling the air during the summer

[54] Twelve Years of School Building Ventilation, *The American School Board Journal*, Vol. 68, p. 56 (1924).

and perhaps this procedure is quite as practical, though more expensive usually and perhaps quite as important from the point of view of hygiene, as heating air in the winter. The passage of the air through a humidifier would affect an appreciable degree of cooling as above pointed out, and in a more elaborate plant the incoming air might be cooled by passing it over coils in which cold water or brine is circulated. A few such plants are in operation throughout the country and it would seem that they should recommend themselves for more general adoption.

There has been a good deal of legislation in the past relative to ventilation standards and there has been sufficient difference in the codes of the various states to show that there is no agreement on the problem. It would seem that before any radical steps were taken looking toward wide departures from what in the past has been considered more or less standard methods of precedure a good deal of data should yet be collected. It is said that the cost of installation of a mechanical system of ventilation is approximately 16 per cent of the cost of the building and there is little or no difference between its cost and the cost of the new system of uncontrolled ventilation.

As a matter of fact the cost is a relatively insignificant matter. Just as the patient is the most important consideration in the hospital so the student is the most important consideration in the school and if we wish to put the matter solely on a monetary basis we might take Fisher's estimate of the value of a human life made some years ago in which he estimated the average worth of a child of five years of age at $950, at 10 years of age at $2000, and at 20 years at $4000. Let us note the average age of our student body in the school in question, multiply it by the number of students in a room and that by the number of rooms in the school and we shall very shortly arrive at the factor of greatest moment and greatest value even when humanitarian ideas are excluded.

The absolute necessity for the cooperation of men trained in all fields which bear upon the problem is essential before any radical changes likely to affect the health of school children should be permitted. The following quotations may be helpful in showing the great importance for the closest cooperation by men engaged in attempting to solve scientific problems. That this is absolutely necessary must be apparent from the statements of the authorities that have been cited. The New York State Commission on Ventilation has done the country a good service in bringing this subject so prominently before the people, but the conclusion reached must be looked upon as a beginning rather than a final solution of the problem of ventilation.

> For instance, ether had been discovered in the 13th century, but its value as an anaesthetic was not definitely recognized until 1846. During the intervening five or six hundred years untold suffering resulted from lack of knowledge of its application in producing insensitiveness to pain. Magnesium sulphate was well known to chemists in 1694, but two hundred years elapsed before it was learned what great relief it gave in lockjaw, burns and strychnine poisoning. Twenty-three years elapsed between the discovery of amyl nitrite by the chemist and the discovery of its medicinal properties by the physician; during this period tens of thousands of human beings suffered the tortures of angina pectoris because the chemist, pharmacologist and physician were not working together.[55]

It is work of this character leading step by step to the complete understanding of the most complex action of our body by the application of the principles of physics and chemistry which sustains the faith of those who believe that chemists and phys-

[55] The Future Independence and Progress of American Medicine in the Age of Chemistry, A Report of the Chemical Foundation, p. 9.

icists working in the closest cooperation with the experts in the various fields of biology, will ultimately express all the major facts of the material side of life in their own exact terms and thereby give to medicine the control characteristic of an exact science. How necessary such encouragement of the faithful army of scientific workers is, must be apparent from the way in which so eminent a physiologist as Haldane of Oxford in spite of his brilliant work, carried out with the aid of physics and chemistry, on the fine adjustment of respiration to environment, despairs of the complete success of the fundamental sciences in explaining the automatic adaptation of the body to its life needs and to its own reproduction and falls back on metaphysical conceptions.

We need but recall that every modern machine, from the power engine to the loom, from the printing press to the watch, is equipped with numberless automatically working devices of fine control and self-adjustment (such as the self-adjustment of a fine watch to temperature changes, by which winter and summer alike it will not vary a second in the ticking off of time). To the barbarians these man-made machines are as wonderful and complex, because not understood as are indeed the marvelously fine sensitive powers of adjustment of the living organism to us, who still understand so little about them. Our problem without question is a tremendously complex one, but the advances already made are sufficiently brilliant promise of ultimate success, and we can best hasten the advance by bringing together for closest cooperative work expert workers to form a small, well-organized corps, where in the past advance has depended most largely on the brilliant but dispersed sorties of the individual worker.[56]

The Power of Knowledge versus Theory—These are but a few of the extraordinary important problems of chemistry and physics in the ultimate field of cell life. They are tremendous problems but many believe they are not beyond the power of the human mind in control of the scientific tools of chemistry and physics. Indeed, until these exact sciences do shed more light on these problems, there will be speculation, theory, philosophizing of many workers to attain this knowledge, but who can question for a moment that complete success in these problems would spell for mankind health of the mind, and the happiness of untold millions of sensitive beings! And based on this knowledge, the medicine of the future will finally succeed in attaining its present noble goal, to prevent disease, to maintain health, so that to a less degree there will be need of the combating of disease.

We still must adhere to the profound advice of Bacon: "Nature is to be commanded only by obeying her."[57]

It seems reactionary from the standpoint of the engineer to institute a method which cannot be controlled. While the method which is in use in the majority of the cases at the present time is not perfect and is open to improvement it does seem as was rather tersely put by one of the prominent members of your Society at the Buffalo meeting:

> This crude theory of window ventilation occupies the same relation to modern methods of mechanical ventilation that the old sailing vessel bears to the superb modern trans-Atlantic liner.[58]

If I may be permitted to make one suggestion in closing it would be that this very complex problem needs more study from the point of view of the physician, the engineer, the physicist, the public health man and particularly the physiologist and physiological chemist, and all the rest and that these experiments should be conducted not with a view to gaining theoretical knowledge which is of doubtful application to the practical problem of ventilation—experimental work in the laboratory and in the calorimeter is all very well—but experience on a broader scale with school and other populations in various sections of the country carefully controlled are much better than work of doubtful transfer value under conditions that do not obtain in every day life.

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[56] The Future Independence and Progress of American Medicine in the Age of Chemistry, A Report of the Chemical Foundation, p. 49.

[57] The Future Independence and Progress of American Medicine in the Age of Chemistry, A Report of the Chemical Foundation, p. 56.

[58] JOURNAL OF THE AMERICAN SOCIETY OF HEATING AND VENTILATING ENGINEERS, F. P. Anderson, March, 1926, p. 143.

XUM

The question merely resolves itself into whether or not we desire a certain type of air for our rooms or, perhaps more correctly, is a certain type of air more advantageous to health than another type? It will be apparent that if there are air conditions which might be termed *optimum* these cannot be obtained by any haphazard means, where people are crowded together, such as by simply opening the windows. If we find that it is desirable to have a certain type of air, and a certain amount of it, there is little question in anyone's mind but that if these conditions can be determined definitely and scientifically, the type of air which is desired can be delivered by mechanical appliances.

We need *controlled*, conditioned air, just as we have controlled conditioned milk or controlled conditioned water. As Isaac Newton said:

> I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble, or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.[19]

[19] Brewster's Memoirs of Newton, Vol. 11, Chap. 27.

IN MEMORIAM

Names	Joined the Society	Died
Edmund G. Bailey	May 1924	Nov. 1925
William E. Benoit	June 1919	May 1926
Wallace E. Boardman	May 1923	Oct. 1926
Clifford R. Bradbury	June 1904	June 1925
Stephen J. Brown	June 1919	Oct. 1926
F. Broadhurst Craig	Dec. 1922	June 1926
Clifford F. Crosby	Dec. 1924	Oct. 1926
Frank A. Dwyer	Dec. 1902	June 1926
William R. Jones	Feb. 1922	Feb. 1926
Clarence V. Kellogg	June 1900	May 1926
Foster W. Lamb	Dec. 1906	Oct. 1926
Joseph F. Musselman	Nov. 1917	Jan. 1926
Oliver M. Row	Jan. 1912	Oct. 1926
W. J. Santmyer	Sept. 1921	Jan. 1926
J. B. Stanwood	Mar. 1924	Oct. 1926
Ira S. Stark	June 1920	Nov. 1926
Thomas Worthington	June 1922	Sept. 1926

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